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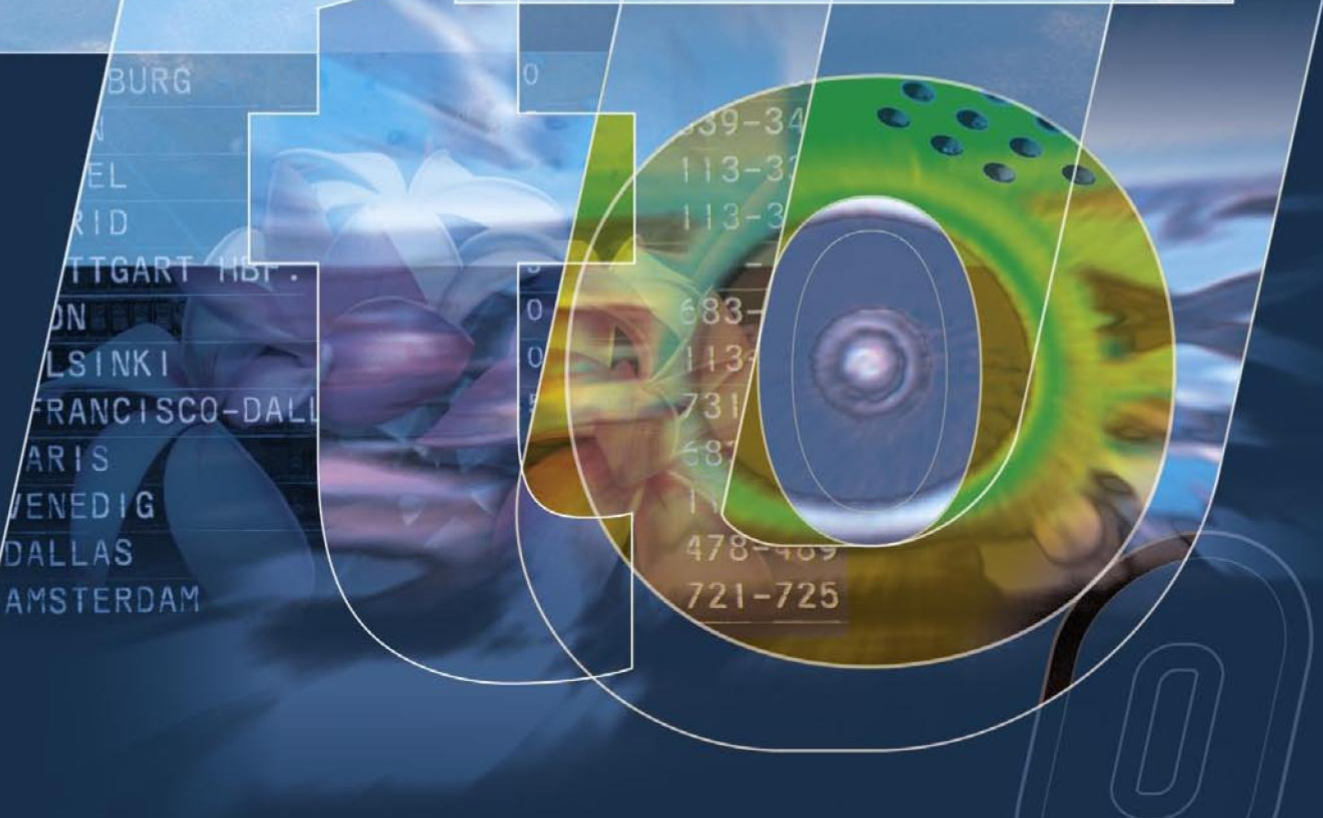

Data Link Business Case Study

Qualitative analysis of potential applications of CPDLC in the Amsterdam FIR below FL245

Report

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Contents

1 Introduction

Data link in aviation is the digital exchange of messages between ground and airborne stations. It covers a wide range of different applications and has been in operation for several decades for airline operations control (AOC) and maintenance. Since the late eighties of the previous century, data link applications for Air Traffic Services (ATS) have been studied and implemented, initially in oceanic airspace. Following various research projects (PETAL, LINK2000+) Maastricht Upper Area Control Centre (MUAC) has successfully implemented Controller Pilot Data Link Communications (CPDLC) in high-density airspace over Europe as a supplementary means of communication in the upper airspace since 2004.

So far, wide scale application of ATS data link in Europe has been limited. However, this may be about to change, as CPDLC is considered to be an enabling factor for new operational concepts for ATS foreseen with the introduction of the Single European Sky. In anticipation of these new operational concepts, the European Commission adopted the Data Link Services Implementing Rule (EC, 2009), hereafter DLS IR, on January 16, 2009. For airspace users the DLS IR states that new aircraft delivered from January 1, 2011 onwards shall be equipped with CPDLC. Existing aircraft shall be retrofitted with CPDLC no later than February 5, 2015, with some exemptions for aircraft due to retire. For Air Navigation Service Providers (ANSP) the DLS IR mandates installation and usage of CPDLC from FL285 an up starting February 7, 2013.

The Knowledge and Development Centre (KDC) has the ambition to study the potential application of data link for the Schiphol operation and put the subject on the KDC Research Agenda (KDC, 2012) as project (PRJ-) 1945. For the execution of the work both To70 and NLR were hired as contractors. This document reports on the To70 work (see paragraph 2.1).

The reader is expected to have a general knowledge of the current ATS operation, future ATM concepts and data link (CPDLC).

2 Research question and approach

The DLS IR mandate applies to upper airspace, which is not controlled by Dutch ANSP, LVNL. There are several reasons however, to investigate if the usage of data link in LVNL controlled airspace would be beneficial:

- The majority of flights in LVNL controlled airspace will be CPDLC equipped as of February 5, 2015 because of the DLS IR mandate;
- It is expected that the FL285 limit be only temporarily, because the SESAR Concept of Operations (SESAR, 2008) assumes progressive replacement of voice communications by data link, also in the lower airspace and terminal area as of 2020.

In the absence of a formal mandate, KDC has asked to investigate if the currently mandated technology allows for fruitful application in lower airspace as well. If the benefits thereof can be demonstrated, this could be reason to consider implementation in the near future.

2.1 Research question

The KDC Research Agenda (KDC, 2012) has defined the research question for this study as follows:

With the advent of full (or near full) airline data link equipage in accordance with the Data Link Services Implementing Rule, investigate which data link services are beneficial to the Schiphol operation (below FL245) and are implementable in the 2013 – 2016 time frame. Make an initial business case in which implementation costs and benefits are evaluated.

During the bidding phase for the project KDC decided to split up the business case in two parts:

- A qualitative assessment of feasible CPDLC applications in LVNL controlled airspace, prioritised based on expected benefits and implementation time frame. This part of the work was awarded to To70 and is reported in this document.
- A more detailed assessment of costs and benefits for the most promising CPDLC applications identified in the first phase. This part of the work was awarded to NLR and will be reported in a separate document.

2.2 Scope

The scope of this study is limited to Controller Pilot Data Link Communication (CPDLC), a data link application that allows for direct exchange of text messages between ATC and the flight crew. This means that other data link applications, such as Automatic Dependent Surveillance Contract (ADS-C), Data link Flight Information Service (D-ATIS, D-VOLMET) and Automatic Dependent Surveillance Broadcast (ADS-B), are not considered hereafter.

2.3 Research approach

To identify the data link services with a potential benefit for the Schiphol operation the following research approach is chosen (Figure 1).

Figure 1: Workflow

The work is executed in three consecutive steps:

1. Exploration of the Implementation Rule (EC, 2009). In this first step the content of the Data Link Services Implementation Rule (DLS IR) is analyzed. Based on this analysis those CPDLC elements and characteristics are described which are most relevant within the scope of this study, in particular regarding technical infrastructure and CPDLC services and messages.

This is done through literature review and a visit to Eurocontrol's Maastricht Upper Area Control Center (MUAC).

2. Investigation of potential data link applications. In the second step potential CPDLC services to support the LVNL operation below FL245 are identified. This involves investigating, for each phase of flight, the operational scenarios that can be supported by CPDLC services and messages on a functional basis. In other words, this step identifies those operational applications for which CPDLC services and messages exist.

This is done through project team brainstorm sessions and desktop analysis of applicable CPDLC messages.

3. Evaluation of feasible data link applications. This step actually consists of two sub-steps:

   a. For each potential application from the previous step it is investigated if operational requirements for the application can be met, in terms of the expected end-to-end data link performance and controllers' way of working. This results in an overview of feasible data link applications.

This work is done through project team brainstorm sessions and comparison with performance figures from literature and experienced by MUAC.

   b. As a final step the operational applications of CPDLC that were found to be feasible are qualitatively evaluated with respect to expected benefits and implementation timeframe. Based on these two evaluation aspects a priority list is produced.

This part of the work is done through project team brainstorm sessions and expert judgment. The most promising applications from this priority list will be investigated separately by NLR to produce the full Cost Benefit Analysis (CBA).

3 Controller Pilot Data Link Communication (CPDLC)

This chapter briefly discusses the European CPDLC mandate, the required technical infrastructure, the CPDLC services, messages and performance. More detailed information can be found in the relevant references indicated in the text.

3.1 European Data Link Services Implementation Rule (DLS IR)

Commission Regulation (EC) number 29/2009 presents the requirements for data link services for the single European sky. The mandate requires both airspace users and air navigation service providers (ANSP) in the European upper airspace to have the capability to exchange CPDLC messages via the Aeronautical Telecommunications Network (ATN) with VHF Data Link (VDL) Mode 2. The ICAO Aeronautical Communications Panel (ACP) has developed standards for ATN and VDL Mode 2 in the 1990's to provide high integrity and performance in aeronautical data link communication. The European Commission considers ATN with VHF Data Link Mode 2 the only validated solution for harmonised deployment in the high density European airspace.

The mandated geographical coverage and implementation schedule are shown in Figure 2.

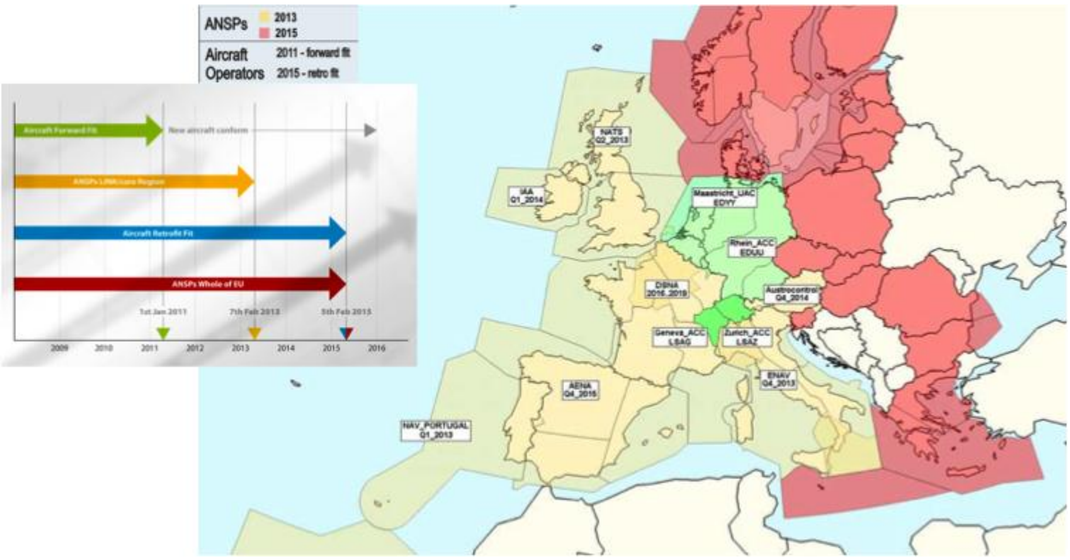

Figure 2: European CPDLC implementation schedule and geographical coverage

Maastricht and Karlsruhe UACs are already operational CPDLC users. The other European ANSPs in the upper airspace, except for those in the former Republic Yugoslavia, are expected to have CPDLC capability operational by 2013 (yellow area) and 2015 (red area), respectively. So far, the UK, Portugal and Italy have indicated that they will meet the target implementation date.

Aircraft operators have been required to operate new aircraft with CPDLC since 1 January 2011 (forward fit). Aircraft built prior to this date will have to be equipped with CPDLC as of 5 February 2015 (retro fit). Exemptions are given to aircraft that are about to be phased out (i.e. before the end of 2017). Aircraft equipped with data link capability using standards known as Future Air Navigation Systems (FANS 1/A), are exempted from installing VDL Mode 2 equipment if the aircraft was built prior to 2014. This is because it is considered economically unjustified to install further data link equipment on such aircraft.

Boeing (FANS-1) and Airbus (FANS-A) developed FANS-1/A equipment in the late 1990s primarily for the long haul models operating in oceanic airspace environments. In this environment data link provides obvious benefits over the traditional means of High Frequency (HF) voice communication, so that data link has taken over the role as primary means of communication.

3.2 Technical infrastructure required for CPDLC

The technical infrastructure required to facilitate the exchange of messages between the airborne and ground based end users is shown in Figure 3. The three different components shown in the figure are:

- Communication network;
- Airborne users; and
- Ground users.

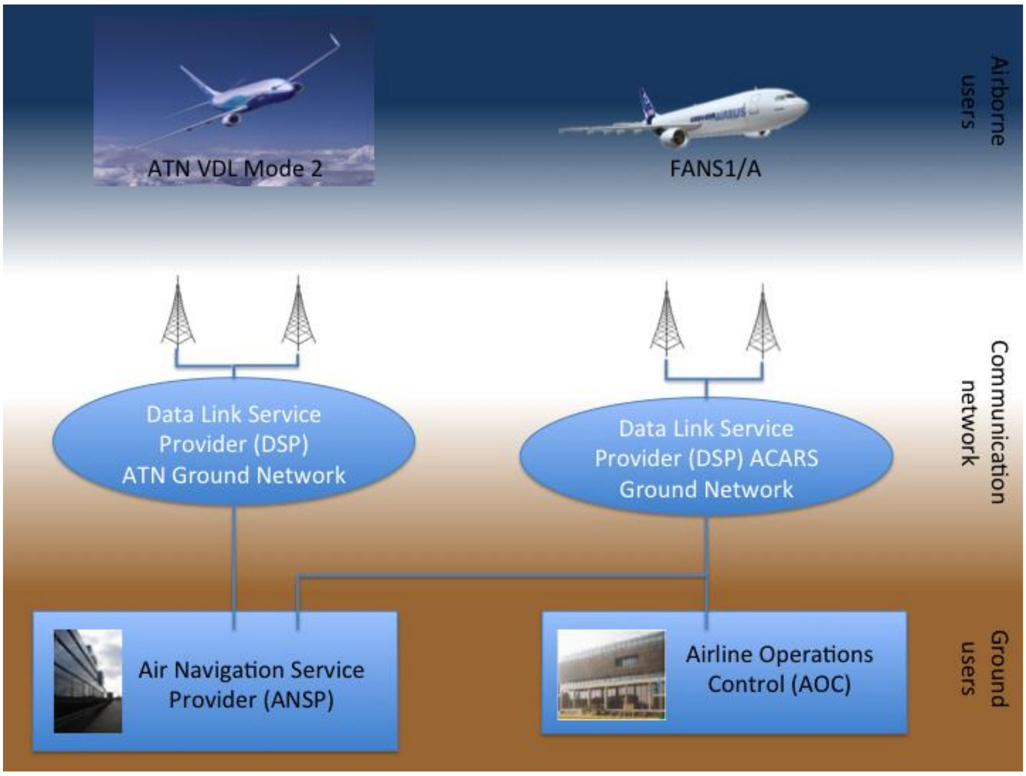

Figure 3: The technical infrastructure required for CPDLC.

Each of these components will be explored below.

Communication network

The communication network is the linking pin between airborne and ground based end users of the data link functionality. The communication network involves networks of ground stations, protected frequency bands and protocols. Networks providing VDL Mode 2 service have been deployed by ARINC and SITA in

Europe since the mid 2000's with different levels of coverage (see Figure 4). This network will have to be expanded in the next years to meet the requirements in the implementation rule. VDL mode 2 provides higher performance than technologies like HF, Satcom or even VDL-A used for ACARS. This does however require the installation of additional or different communication equipment on-board the aircraft. For the remainder of this study, the communications network is considered as a black box that cannot be adapted.

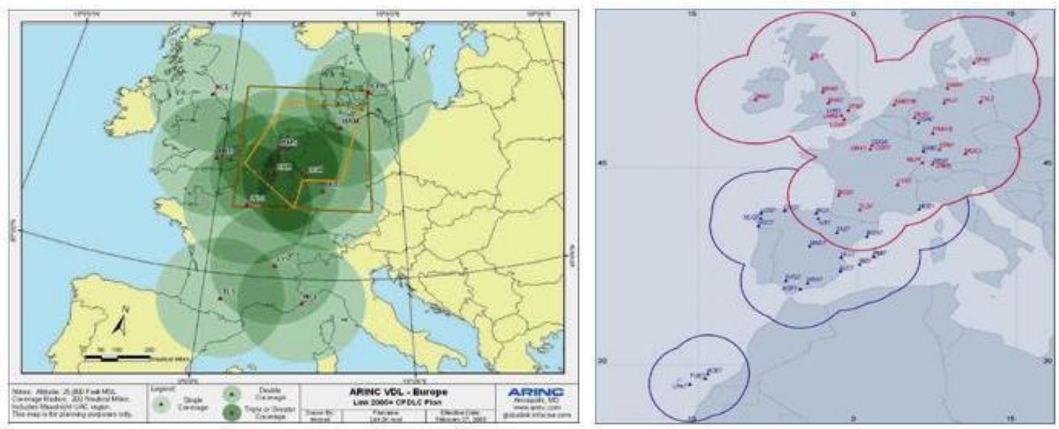

Figure 4 – Left: European ARINC GLOBALink VDL Mode 2 coverage; Right: European SITA Aircom VDL Mode 2 coverage (EURCONTROL, 2013).

Airborne users

On the airborne user side, pilots make use of CPDLC via the Human Machine Interface (HMI) in the cockpit. The HMI input device is connected to Communication Management Units (CMU) which can send and receive data link messages through a number of communication media (e.g. VHF, HF, satcom).

The crew takes initiative by logging-on to an ATC centre by placing a connection request. A connection request can be placed in advance, but only becomes active at about 10 to 15 minutes prior to entering the airspace of the ATC centre involved. The centre to which an active connection is maintained is referred to as the 'current data authority'. The system automatically recognizes the next data authority to be switched to. When a connection is successfully established the crew can receive data-link messages from the ATC centre, or place a request with the ATC centre.

Ground users

The ground system in support of CPDLC data link communications typically consists of an HMI for the controller, a Flight Data Processing System and the Data Link Gateway to facilitate *communication.*

3.3 CPDLC services and message elements

The data link requirements of the mandate are contained in the DLS IR. In order to provide a Means of Compliance (MOC), EUROCONTROL has issued a specification on Data link services (EUROCONTROL, 2009). The intent of this document is to enable data link users to reach the interoperability targets specified by the IR. To this end, the EUROCONTROL data link specifications make extensive use of references to external standards and documents maintained by ICAO, EUROCAE and the AEEC. The scope of these standards however is wider than the scope of the IR.

Data link services

The CPDLC capabilities are offered through a series of data link services, each with their own specific characteristics:

- Data link Initiation Capability (DLIC)
- ATC Communication Management (ACM)
- ATC Clearances (ACL)
- ATC Microphone Check (ACM)

Each service in turn is comprised of several data link message elements (Downlink and Uplink). In that sense, a data link service can be seen as a specific communication functionality that is implemented by means of sending and/or receiving data link messages elements. The four distinct data link services mandated by the IR will be described in this section.

<u>Data link Initiation Capability (DLIC)</u>

DLIC is a data link service providing the necessary information to make data link communications possible between an ATS Unit and aircraft. It is therefore the enabling service for all the other data link services, required to be able to perform CPDLC communication.

The DLIC service is initiated by the aircraft and ground systems will respond to the “Logon” service. Note that the objective is to enable an aircraft to log on only once while traversing data link airspace. Once the aircraft has logged on, the parameters for data link communication will be passed between adjacent centers, using ground-ground inter-center co-ordination. Therefore subsequent centers along the route will establish CPDLC services without using DLIC service.

The DLIC service makes it possible to:

- Unambiguously associate flight data from the aircraft with flight plan data stored by an ATS Unit.
- Exchange the supported application type and version information and deliver application address information.

The Logon function of DLIC allows the aircraft to initiate data link service. The Contact service allows the ground system to request that aircraft logon with another ground system. Once logged on and while traversing data link airspace, the process of transferring the CPDLC connection from one unit to the next ATC unit or centre occurs automatically without any need for manual intervention by the flight crew. This means that, while the aircraft progresses through data link airspace no additional actions will be required by the flight crew to maintain data link service.

ATC Communication Management (ACM)

The ACM service provides automated assistance to flight crew and controllers for conducting the transfer of ATC communications (voice and CPDLC), respecting the operational rule that there is only one ATC controlling authority at any given time.

The ACM service permits:

- the initial establishment of CPDLC service between an aircraft and an ATS Unit;
- the transparent transfer of data communications, concurrently with the transfer of voice communications for a flight from the transferring ATS Unit to the next ATS Unit, or the instruction to change voice channels within an ATS Unit or sector;

This service will permit the reduction of RT-load in situations where Transfer Of Communication (TOC) instructions constitute a significant portion of the RT-load for a sector frequency. The transfer of communication RT is effectively off-loaded to a second communication channel. For example, at MUAC the use of the ACM service has contributed to lowering the RT-load on their sectors.

It is conceivable that the controller will have two methods of releasing a flight to the next unit available to him/her. One method is the existing REL-function to which a new one could be added that performs the same action as the existing REL function but also sends the contact next ATS unit CPDLC message automatically if the situation permits. Future applications of this capability could include automatic system initiated transfer of communication under strict conditions.

ATC Clearances (ACL)

The ACL service allows flight crews and controllers to conduct operational clearance exchanges. The ACL service permits:

- flight crews to make requests and reports to controllers;
- controllers to issue clearances, instructions and notifications to flight crew.

Within LVNL airspace, the ACL service provides an additional communication channel for the controller to convey clearances.

For clearances that are not (yet) included in the ACL message set, it is possible to communicate any ATC clearance by means of a free-text message. The response to a free text message can only be "ROGER" or "REJECT", which means that the message is understood, but not necessarily will be complied with. An Uplink Message element other than "Free text", can be responded to by means of a "WILCO" reply, signifying to the controller that the clearance will be complied with.

ATC Microphone Check (AMC)

The AMC service allows a controller to send an instruction to all CPDLC equipped aircraft in a given sector at the same time, in order to instruct flight crews to verify that their voice communication equipment is not blocking the sector's voice channel. Having CPDLC provides an independent communication channel since it is completely separate from the RT infrastructure.

Data link message elements

For each of the data link services a number of Uplink and Downlink Message Elements are defined. These are given in Annex A of the EUROCONTROL Data link specification. They are derived from the “Baseline 1” specification for continental airspace in EUROCAE Documents ED-110B and ED-120. This is a subset of the message elements defined in ICAO Doc. 4444 by ICAO.

The most extensive and most important list of uplink message elements is defined for the ACL service. This list can be found in Annex A of the EUROCONTROL Data link specification, Table A-3. In an uplink message (UM), up to five "message elements" can be combined. For example, a DCT instruction is an element and a CLIMB instruction also constitutes an element. The most important consideration for the use of this mechanism is that the message is treated as a whole. That means that if the crew replies with WILCO or UNABLE to the message, this reaction applies to all elements of the message.

4 Potential data link applications

This chapter describes the identification of potential data link applications. Data link applications are considered to be a potential application when information exchange between ATC and the flight crew can be exchanged via data link. In the end a list of potential applications is given which will be assessed for feasibility in chapter 5.

4.1 Scope and approach

The scope for this study is limited to the application of data link below FL245 (LVNL controlled airspace). An information exchange outside LVNL controlled airspace that affects the operation within LVNL controller airspace is not considered within the scope of the study.

To determine potential CPDLC applications below FL245, the information exchange between responsible executive ATC functions and flight crew is identified (indicated in Figure 5). Consequently, it is assessed whether this information can potentially be exchanged by data link. The following steps are followed:

- Subdivide by phases where the flight is under responsibility by a particular ATC unit;
- Describe responsibilities of the ATC unit;
- Identify information exchanges between ATC and flight crew;
- Determine whether this information can also be exchanged via data link;

The potential of CPDLC is discussed for the two distinct planning activities: the departure planning and the arrival planning. These planning activities will be described prior to the description of each of the phases in detail in order to provide the overall planning context.

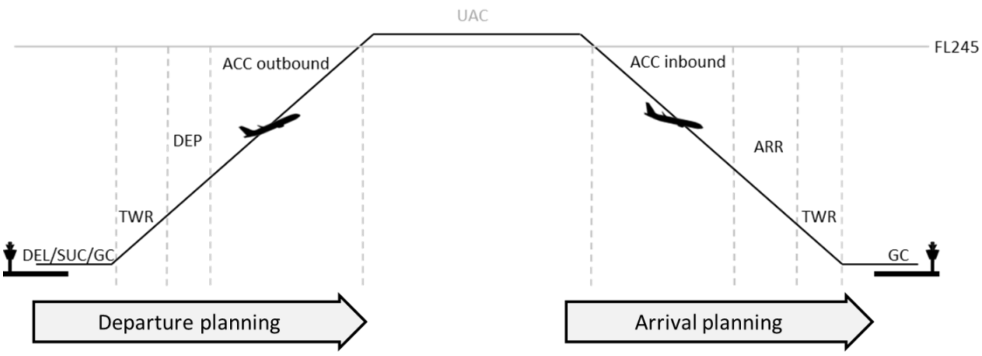

Figure 5: Subdivision per responsible ATC unit in the current operation

The identification of potential applications starts by identifying processes of information exchange between ATC and flight crew, with a strong on focus on the exchanges taking place in the context of flight (trajectory) planning.

4.2 Outbound and inbound planning processes

In this section potential CPDLC applications will be identified for the departure and arrival process by first looking at the complete planning process and the operational functions involved in the handling of outbound and inbound traffic.

Outbound planning process

Each of the ATC functions during the departure process has specific responsibilities and processes of information exchange. The outbound planning process is primarily performed by the Start-up Controller (SUC). The SUC performs the task of planning the actual departure sequence from Schiphol. Originally this task had little systems support other than presenting a long list of flights that would be requesting start-up within an hour. However, recently automation has been developed that provides the start-up controller with target start-up times to assist in this planning process. This automation will take all the available information into account to derive an efficient planned departure sequence incorporating CFMU constraints and any other constraints that may apply, like the time by which an aircraft is expecting to be ready. The other actors in the Control Tower will subsequently use this information to guide their decisions.

Inbound planning in the arrival process

The arrival process is governed by the Inbound Planning (IBP) process. This process consists of automation logic that determines the arrival order (sequence) and meters the amount of traffic that can be accommodated in the Schiphol TMA at any given time. To that end, the IBP logic calculates planned arrival times and subsequently planned times of entry into the TMA: the Expected Approach Time (EAT). The EAT can be viewed as a time window within which ACC is to deliver arriving traffic to APP. The Approach Planner manages the IBP logic. He is responsible for providing the correct parameters as well as any manual corrections to the automatic planning process.

Currently, the arrival-planning phase is initiated just before or just after initiation of the top of descent. In the future, ACC will be assisted by a Speed and Route Advisor (SARA) system that will assist ACC controllers in achieving (narrow) EAT windows by means of advised speeds and routes. Initially these will be provided and effectuated during the arrival stages and therefore be more tactical in nature. As the planning horizon of the IBP is extended clearances based on the arrival planning can be issued earlier and therefore coincide better with the arrival planning activities on the flight deck, facilitating a more flight efficient and predictable operation.

This implies that other centres will become involved in the establishment and communication of the corresponding clearance. This in turn needs be accompanied by further ground-ground integration permitting the exchange of relevant flight plan details and clearances with such centres. As discussed earlier, such clearances become increasingly more suitable, and often a necessity, for communication by means of CPDLC. In summary, this means that the actual message exchanges will typically occur outside of LVNL airspace (and will therefore not require CPDLC applications in the Amsterdam FIR below FL245).

4.3 Identification of potential CPDLC applications in the departure process

Whether an information exchange between ATC and the flight crew is a potential CPDLC application, depends on the type of information and whether CDPLC supports the exchange of this information. The paragraphs below describe the responsibilities of the controller and the information exchange for each phase in more detail. Consequently the identification of potential applications follows from the process of information exchange between controller and flight crew.

Delivery controller

Responsibilities

Prior to start-up, the flight crew contacts the delivery controller (DEL). The DEL is responsible for checking flight plans, providing en-route clearances and communicating the calculated take-off time (CTOT) for departing flights. The clearance and the CTOT have a non-tactical nature since they serve as planning support information for the flight crew. Both types of information are typically communicated (at least) 25 minutes prior to the expected off-blocks time (EOBT).

Process of information exchange

The DEL provides the flight crew with an en-route clearance and CTOT. These are communicated either via radio telephony (RT) or AOC data link. An en-route clearance at Schiphol includes at most five elements: the clearance limit (airport of destination), standard instrument departure (SID) and designated departure runway, SSR-code, additional instructions if applicable, and CTOT. An example of a clearance (by RT) is given below:

"KLM123 cleared to Paris, LEKKO 1S Departure, runway 24, squawk 2123, CTOT 1425"

In response to this clearance, the flight crew reads it back to confirm correct understanding of the clearance. The DEL then gives the flight crew an instruction to contact start-up control. In case the clearance is requested and received by AOC data link, the flight crew also accepts the clearance via AOC data link and transfers to the start-up controller’s frequency without instruction from the DEL. In off-peak hours the role of the DEL is combined with that of the start-up controller (see next paragraph).

Potential applications

The mandated CPDLC message set for ACL includes the possibility for providing route clearances. The route clearance can be combined with free text messages from the ACL service for sending additional information like the CTOT or SSR-code. The ACM message set enables TOC by CPDLC. In addition to supplementing and/or replacing the existing information exchange, the AMC service can be used in case of a stuck microphone blocking the frequency. For that matter, the en-route clearance, CTOT communication and Mic check are potential applications for the delivery controller.

Start-up controller

Responsibilities

The start-up controller (SUC) ensures a safe and efficient distribution of departing flights and is an important link in managing the outbound traffic flow (see section 4.1). A SUC provides the start-up clearance and the most recent ATIS letter together with aerodrome information.

Process of information exchange

When the flight crew is ready for start-up, they contact the SUC and request start-up clearance. The SUC determines whether the start-up approval can be given based on the anticipated pushback, start-up and taxi times, start interval and CTOT. There is an increasing use of system automation to assist with this task, in the form of a calculated Target Start-up Approval Time (TSAT). If there are no restrictions, the start-up approval is given by RT together with the active ATIS information. TOC to Ground Control (GC) is mostly combined with the start-up clearance in order to guarantee continuous and efficient transfer of flight from the SUC to the GC. A typical start-up clearance:

"TRA456, start-up approved, information R, contact ground 121.8."

If it is anticipated that departure delays will occur near the runway, the SUC may clear for start-up at a particular time. In such situations the controller may provide the number in sequence on his own initiative or on request by the pilot.

"TRA456, stand by to start, expect start-up within 10 minutes"

Potential applications

By means of a free text message, the ACL service provides the possibility to send the ATIS letter, aerodrome information, TSAT and TOBT. Transfer of communications (TOC) can be performed by means of a CONTACT instruction from the ACM service. As for the DEL, the AMC service is available to the SUC in case of a stuck microphone blocking the frequency. The start-up clearance cannot be considered a potential application since it is not supported by the ACL service and cannot be provided by means of free-text since it needs to be WILCO-ed. Different local ground infrastructure (i.e. RT) is used for communicating this type of information.

Ground Controller

Responsibilities

The ground controller (GC) is responsible for ensuring a conflict-free ground operation and enabling maximum usage of the ground capacity in the manoeuvring area.

Process of information exchange

For departing flights the GC provides the pushback clearance and provides instructions from the parking stand to the runway. To maintain a safe and orderly flow of traffic the controller assesses the situation on the manoeuvring area through visual observation from the tower. When visibility is reduced or the tower is in clouds, ground radar is used for this purpose. When ready for taxi, the crew requests a taxi routing from GC. The GC provides the taxi route to the designated departure runway:

"MPH789, taxi to runway 36L via taxiway B and C, cross runway 36C at W5"

During taxi the crew may also receive tactical instructions to control the right of way and taxi routing deviations. Flights are transferred to another GC when the flight is approaching the area of responsibility boundary by either a CONTACT or MONITOR instruction or to the Runway Controller when the flight approaches the departure runway. The GC can issue taxi instructions to runway intersections to provide initial sequencing such that the RC can achieve an optimal departure flow.

Potential applications
Given the fact that the taxi routing is a long instruction, it could be beneficial to have this message available. However, the ACL service provides no messages for taxi routing instructions: the routing messages in the CPDLC message set are intended for airways and waypoints only. The ACL service does not offer functionality for including latitude/longitude information in a routing instruction, which is required for taxi routing. The absence of a dedicated taxi routing message in the ACL service prevents the use of CPDLC for this purpose. From the ACM service, the CONTACT and MONITOR instructions are supported by the message set. Right of way instructions are not supported by the CPDLC message set. The AMC service can be used in case of a stuck microphone blocking the frequency.

Runway controller
Responsibilities
The runway controller (RC) is responsible for the safe operation and efficient flow of traffic in the direct vicinity of the airport (CTR).

Process of information exchange
All flights and vehicles in the area of responsibility of the RC are in direct contact with the RC. The RC provides tactical instructions to maintain a safe and orderly flow of traffic. An efficient traffic flow requires flexibility that can be achieved when clearances and instructions are provided in a tactical way. To support this way of working the RC relies heavily on visual observation of the flights under his control.

The RC informs flights that are ready for take-off on actual wind, Runway Visual Range (RVR) and if applicable on the status of navigation aids. Also additional instructions can be provided in addition to the take-off clearance (e.g. during parallel departure operations):

"KLM123, at 500 feet turn left heading 175, runway 18L cleared for takeoff, remain on this frequency"

If no instruction to remain on the frequency is given, the flight crew will contact departure control when passing 2000 feet.

Potential applications

The take-off clearance and runway crossing clearance are not part of the messages supported by the ACL service and can therefore not be handled by CPDLC. Available messages in the CPDLC message set from the ACL service could be a free text message for communication of RVR, changes in weather information, information on the status of navigation aids and for transfer of control of the ACM service. Also, the AMC service can be used in case of a stuck microphone blocking the frequency.

Departure Controller

Responsibilities

The departure controller (DCO) is responsible for keeping the departing flights separated from each other and from arriving flights. The responsibility of the DCO reaches until the TMA exit when the aircraft are transferred to ACC outbound. The DCO aims at transferring aircraft to ACC as soon as possible.

Process of information exchange

In order to separate arrivals and departures, the DCO provides level clearances for the departing flights such that vertical separation between arrivals and departures can be guaranteed. To mutually separate departing flights, the DCO primarily uses heading instructions. When flights are above 3000 ft[1], the DCO may also give a routing instruction (DIRECT TO, DCT). The separation instructions have a tactical nature (guaranteeing separation) whereas the routing instructions are aimed at transferring flights as soon and as efficiently as possible to ACC. Departures are transferred to ACC when they are free of other departing and arriving traffic. The flight crew receives a TOC instruction from the DCO when they should contact the next ATC centre. During the departure phase the flight crew is working head-up, the ATCo is working head-down.

Potential applications

Looking at the mandated CPDLC message set for ACL, route clearances, heading instructions and level clearances could potentially be used. In the ACM service, TOC is supported; the AMC service can be used in case of a stuck microphone blocking the frequency.

ACC outbound/transit

Responsibilities

In this phase ACC is responsible for transferring the aircraft from the TMA exit points to the FIR exit and to keep civil air traffic separated from military air traffic.

Information exchange

In order to fulfil these tasks, ACC provides heading instructions and level clearances to maintain separation between aircraft. Routing instructions are provided in order to optimize traffic flow. ACC communicates routing and heading instructions, level clearances, if relevant SSR changes and TOC instructions when flights are transferred to Upper Area Control (UAC).

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[1] 3000 ft is the limit during the day. During the night, the limit is FL90

Potential applications

From the ACL service, the routing instructions, heading instructions and level clearances are supported by the mandated message set as well as SSR changes and TOC from the ACM service. The DLIC service includes a message for the flight crew to contact the next responsible ATC centre. The AMC service can be used in case of a stuck microphone blocking the frequency.

4.4 Identification of potential CPDLC applications in the arrival process

ACC inbound

Responsibilities

ACC, in this phase, is responsible for transferring the aircraft from the FIR entry to the IAFs and taking care that flights are transferred to the Approach controller within the scheduled time frame. The scheduled timeframe is determined by the inbound planning functionality of the ATM System and is expressed in terms of an Expected Approach Time (EAT) indicating the time the flight is scheduled to enter terminal airspace.

Process of information exchange

In order to create an efficient arrival stream ACC gives holding, routing and heading instructions and level clearances to arriving flights in order to achieve the EAT window. ACC also communicates SSR changes, the expected arrival time (EAT), and transfer of communication when flights are transferred to approach control (APP). It is expected that within the 2013-2016 timeframe ACC will provide the flight crew with speed updates from the Speed And Route Advisor (SARA) to improve the delivery accuracy, i.e. EAT adherence.

Inside LVNL airspace under responsibility of ACC, changes to the SARA speed schedule are considered as tactical instructions since they are aimed at maintaining separation whilst achieving the EAT window. These are considered building blocks towards a full SARA system spanning the entire descent phase and as such suitable to become part of the planning activity on the flight deck. Once this level of maturity is achieved, the corresponding clearances become candidate for communication by CPDLC. This does imply these clearances need to be delivered by the upstream centres, since the descent is typically initiated under their control.

Potential applications

Looking at the mandated message set for the ACL service, holding instructions, routing instructions (UM74), heading instructions, speed instructions and level clearances are supported. Also transfer of communication from the ACM service and the microphone check from the AMC service are available to ACC. The ACL service enables communication of SSR changes by means of a free text message.

Feeder / Arrival Controller

Responsibilities

The feeder and arrival controllers (FDR/ARR) are responsible for an efficient flow and ensuring separation when lining up arriving flights for final approach in the TMA. The FDR is responsible for separating departing and arriving traffic; the ARR is lining up the arriving traffic for final approach.

Process of information exchange

The FDR/ARR provides routing, heading, speed and level instructions to arriving flights: a highly tactical operation, since efficient and high capacity is realized by flexibility. The FDR will typically also brief the crew on the most recent ATIS letter and update the RVR service. When flights are 'established' on the ILS, communication is transferred to the RC.

Potential applications

The ACL service includes heading instructions, speed instructions and level clearances. TOC is supported by the ACM service. The RVR service can be provided by means of a free text message from the ACL service.

Runway controller

Responsibilities

The runway controller (RC) is responsible for safe operation and efficient flow of traffic in the direct vicinity of the airport (CTR).

Process of information exchange

In case of arriving flight, the RC provides the landing clearance and information on the actual wind conditions. Arriving aircraft should transfer to GC frequency themselves when touched down. In the final approach phase, clearances as well as information on wind conditions should be received in time. This is important to ensure not only safe, but also efficient use of the runway. Actual wind conditions are communicated to the pilot mostly simultaneously with the landing clearance.

Potential applications

The ACL service does not contain messages to provide the crew with a landing clearance, but support using CPDLC services is possible in the form of a free text message from the ACL service. This message could in theory also enable exchange of information on weather conditions.

Ground Controller

Responsibilities

The ground controller, when handling arriving flights, is responsible for taxi routing and additional taxi routing changes.

Process of information exchange

The difference to the operation with departing flights is that there is no push-back clearance involved and arriving flights only receive the stand where to taxi to. The crew will receive the taxi routing to the stand from the GC when exiting the runway. The GC can give additional instructions (i.e. right of way) to taxiing flights if necessary. If aircraft need to cross an active runway, the GC instructs the crews to contact the RC.

Potential applications

As for departing flights, taxi routing instructions could be sent by CPDLC to reduce the RT. The CONTACT and MONITOR instructions are supported by the ACM service.

4.5 Potential CPDLC applications

From the assessment for all ATC functions, the potential CPDLC applications are summarized in Table 1. The DLIC service is assumed to be available for all ATC units, since this is a precondition for using CPDLC.

ATC function	ALC						ACM	AMC
	RTE	ATIS	TSAT/ TOBT	DCT	EFL	SPD		
DEL	X	-	-	-	-	-	X	X
SUC	-	X	X	-	-	-	X	X
GC	X	-	-	-	-	-	X	X
TWR	-	-	-	-	-	-	X	X
DCO	-	-	-	X	X	X	X	X
ACC outbound	-	-	-	X	X	X	X	X
ACC inbound	-	X	-	X	X	X	X	X
APP / ARR	-	X	-	X	X	X	X	X
TWR	-	-	-	-	-	-	X	X
GC	X	-	-	-	-	-	X	X

Table 1: Breakdown of potential CPDLC applications for all ATC functions

The next chapter describes if these applications are deemed feasible within the time frame considered in this study. Consequently a ranking is proposed of the remaining potentially beneficial applications based on expected benefits and implementation time.

5 Evaluation of potential data link applications

This chapter identifies the qualitative benefits and impact on the ATM system for each of the potential CPDLC applications identified in the previous chapter. This information is used in order to establish a priority list that is used by the NLR to investigate quantitative benefits.

5.1 Selecting beneficial CPDLC applications

The previous chapter has shown a number of potential CPDLC applications, looking at the complete gate-to-gate operation. Whether this potential translates into beneficial application is not only determined by the currently mandated CPDLC message set (based on the EUROCONTROL LINK 2000 program for applications in upper area control), but also by the performance of CPDLC and operational suitability.

The performance of a data link exchange depends on the performance of all 'actors' involved. This means not only the performance of the communication channel itself, but also e.g. the swiftness with which controllers and aircrew are able to respond to data link messages. The contribution of these actors in a CPDLC exchange to performance is further described below.

Communication network performance

The communication network for the DLS IR is based on VDL mode 2. Although this can be considered a fast network compared to Satcom and VDL-A for FANS, a noticeable transmission time has to be taken into account in the overall message transaction time.

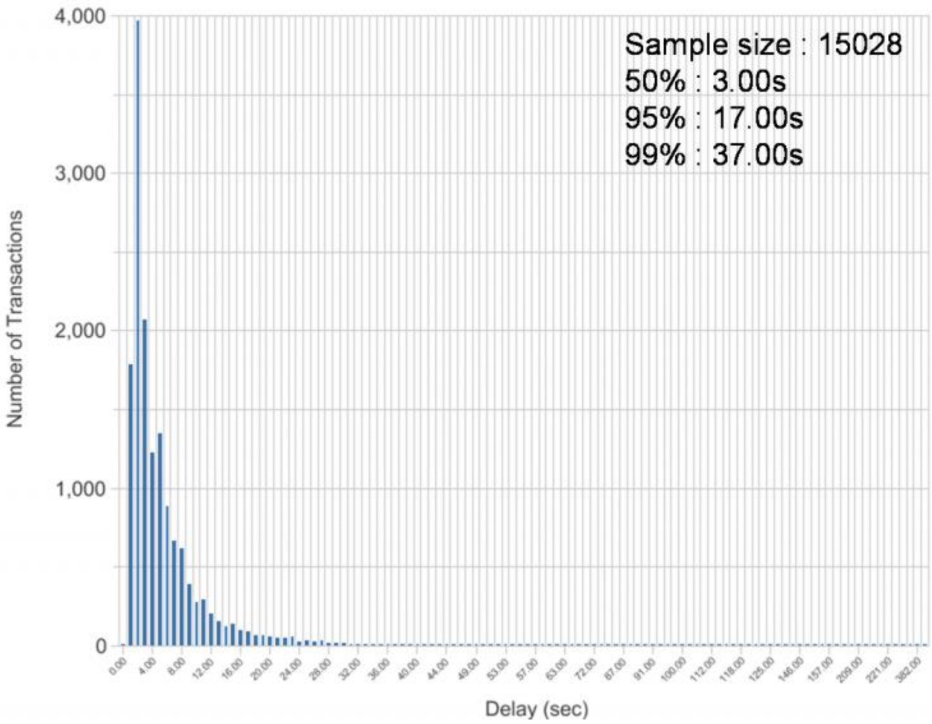

Figure 6: Technical round trip delay for ATN equipped aircraft (source: EUROCONTROL)

Also, EUROCONTROL data shows that network provider aborts occur relatively frequently (on average 10-15% in the last year, see figure below).

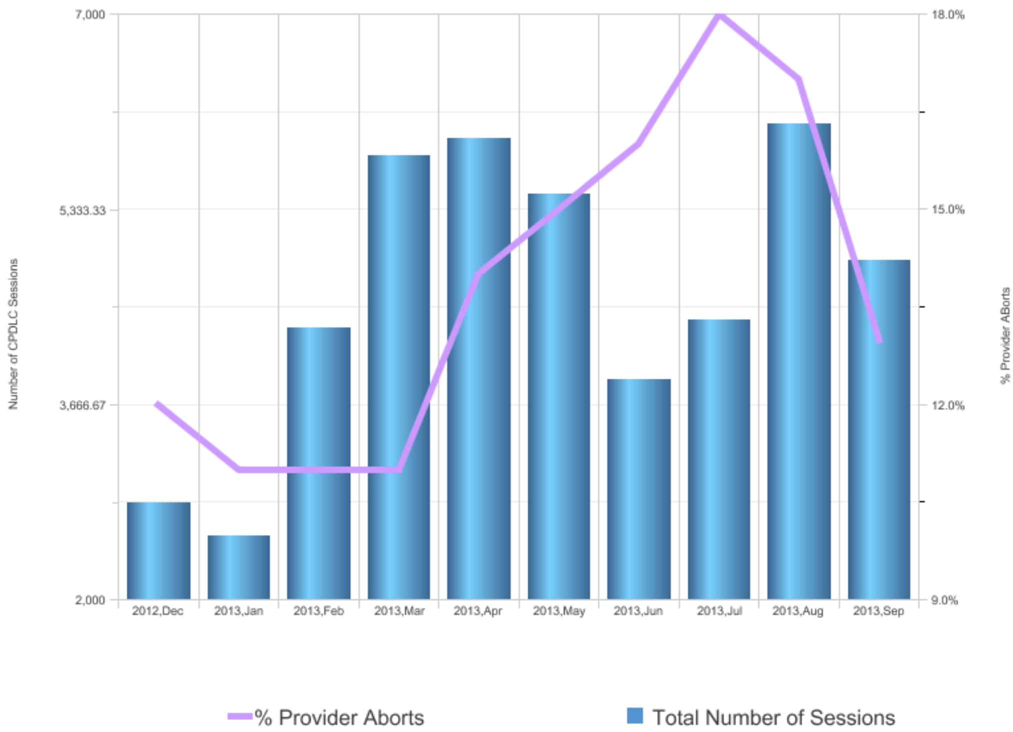

Figure 7: Provider aborts for ATN equipped aircraft (source: EUROCONTROL)

On its website[2], EUROCONTROL publishes monthly uplink and downlink error counts. August 2013 data suggest that uplink errors like "DOWNLINK TIMESTAMP INDICATES FUTURE TIME", "CPDLC MESSAGE FAILED - USE VOICE", "DOWNLINK DELAYED - USE VOICE", "ATC TIMEOUT - REPEAT REQUEST" each occurred in approximately 1% of all uplink communication. The most frequent downlink communication error was "UPLINK DELAYED IN NETWORK AND REJECTED. RESEND OR CONTACT BY VOICE".

Response times of flight crews and controllers

The requirement for flight crews is to respond to Data link Uplink Messages (i.e. from controllers to flight crews) within 2 minutes. The requirement for controllers is to respond to Data Link Downlink Messages (i.e. from flight crews to controllers) within 3.5 minutes. Experience at MUAC has shown that, as exposure to the use of CPDLC is increased, flight crews appreciate the potential of data link and response times decrease. ATN equipped aircraft achieve an average message transaction time of 22 seconds (for FANS a/c this is 35 seconds)[3]. Typically response times start high as crews need to become familiar with the use of CPDLC, however once familiarized, response times become shorter, down to values of sometimes less than 10 seconds. Figure 8 shows a histogram for Skyguide and MUAC data for August 2013.

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[2] https://eurocontrol.int/link2000/wiki/index.php/Last_Month%27s_ATN_Performance_Metrics

[3] Based on presentation by Volker Stuhlsatz (Maastricht UAC) for To70, NLR and Ferway, March 2013

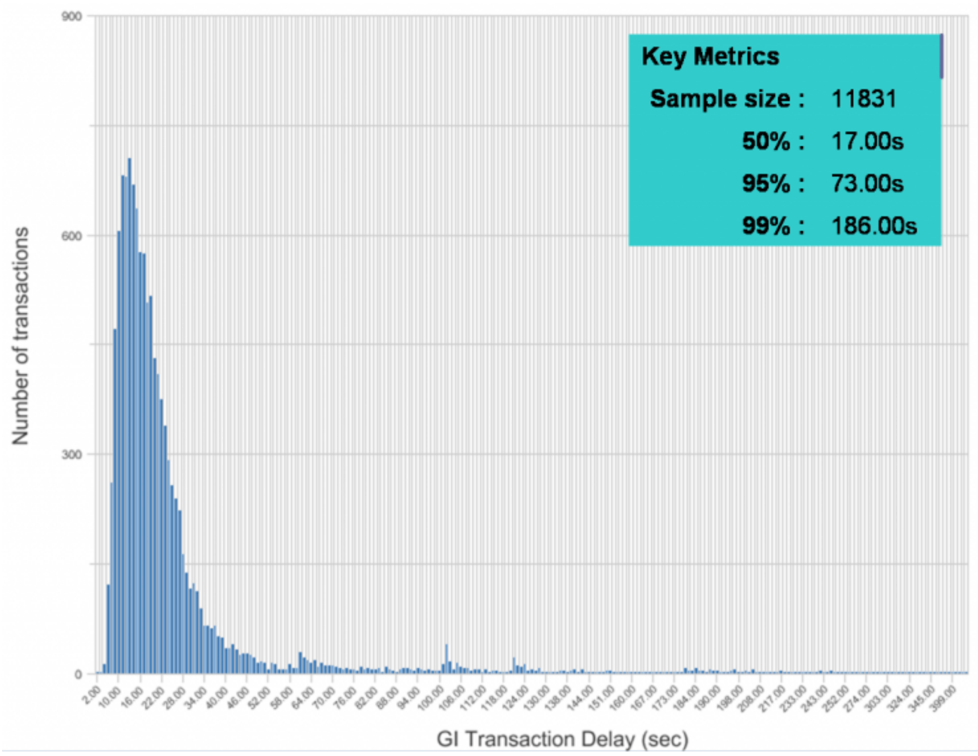

Figure 8: Transaction delay for ground-initiated communication (source: EUROCONTROL)

Operational suitability

In LVNL controlled airspace, it is most likely the time criticality of information and the swiftness of replies to requests that determine whether CPDLC use could be beneficial. Looking at tactical control situations, an almost immediate response is often required to maintain an efficient and safe flow in high density traffic, on the ground as well as in the air. The crew must therefore have the opportunity to reply as quickly as possible in order to perform the requested instruction. The air traffic controller, on his end, should be involved in the communication with each aircraft as briefly as possible. This limits workload and maintains efficiency and safety in the ATM system.

Non-tactical control situations allow for the use of CPDLC for information exchange. This type of information exchange is less time critical and current end-to-end (E2E) performance of CPDLC communication could in some situations show to be sufficient. Typically this will apply to providing non-urgent information and/or clearances. This includes information that is uniformly provided to multiple aircraft, like the current ATIS letter. Therefore, when evaluating the potential of CPDLC to support a specific ATC task involving communication with the cockpit, the time critical nature of this communication is one of the aspects that need to be taken into account. For that reason, the evaluation below focuses on non-tactical operations.

Second, given that free-text messages cannot be replied to by a WILCO response, the use of free-text shall in principle be limited to those circumstances where the message contains information only. For clearance exchanges, it needs to be ascertained that they will either be complied with or rejected by the flight crew. Therefore, operationally, this construct is suitable for and limited to those cases where the controller wants to treat the clearance as a whole and no partial execution is allowed. A typical example is the case of a departing flight contacting Area Control, where ACC would send the message: *"DCT OSN CLIMB FL250"*. If the individual elements of a combined message need to be treated separately by the crew, separate messages need to be sent. These each require their own response (WILCO/Unable). It therefore depends on the type of operation whether this means of communication is suitable or not.

5.2 Evaluation of potentially beneficial applications

In this paragraph, it is assessed if the potential CPDLC applications identified in chapter 4 could prove to be beneficial.

Outbound planning process

Delivery control

The use of the AMC service as independent secondary communications channel in case of a stuck microphone or non-com offers valuable additional functionality for the DEL, resulting in an efficiency benefit. Compared to the current situation, in which DEL has no alternative means of contacting the flight crew, the microphone check via CPDLC is deemed a potentially beneficial application.

Exchanging the en-route clearance by CPDLC is also a potentially beneficial application. System E2E-performance can be considered sufficient. CPDLC messages can be combined to a maximum of five, thus offering sufficient functionality for exchanging the complete en-route clearance. However, it should be kept in mind that, in essence, clearance delivery by AOC data link already offers the same benefits as delivering the clearance by CPDLC: both result in less congestion on the R/T channel, make it easy for the crew to request a clearance without having to wait for the DEL to be available on the R/T channel, and are less error-prone than clearance delivery via R/T.

Start-up control

As for the DEL, the CPDLC services can provide the SUC with a secondary means of communication: the microphone check from the AMC service is considered a potentially beneficial application as well for the SUC considering the efficiency benefit. In theory, communicating the TSAT/TOBT by CPDLC could prevent congestion on the R/T channel, for example during busy hours and/or in case of delays. However, a recent (2013) airport-CDM operational trial at Amsterdam Airport Schiphol has shown that data link is currently not optimally suited for conveying last-minute updates to the flight crew[4]. Therefore, applications regarding TSAT/TOBT are not further considered in this report.

Ground control

The operation on the ground concerning right of way instructions requires fast communication in order to handle traffic safely and expeditiously. Given the current E2E-performance, the use of CPDLC at present seems unfit for such typically tactical operations. The ground operation’s tactical nature keeps the CONTACT and MONITOR instructions from being effectively used. It is therefore expected that within the time frame considered in this study, no operational application of CPDLC for GC can be made feasible

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[4] Amsterdam Airport Schiphol Collaborative Decision Making program, accessed December 2, 2013, http://www.schiphol-cdm.nl/nl/Nieuws_en_media/Nieuws/17-09-2013_CDM_Programma_Update

other than the microphone check provided by the AMC service. The latter provides a safety benefit for GC, since a stuck microphone during taxiing could pose a danger to the operation.

Runway Control
As for GC, the operation of the RC is of tactical nature. Given current E2E-performance, this makes the use of CPDLC unsuitable for efficient operation for this ATC function. Therefore, although TOC and free text are supported by the CPDLC message set, both have to be excluded as potentially beneficial CPDLC applications for the RC. As for the GC and SUC, the only application deemed feasible for the RC is the AMC service (microphone check), considering the safety benefit.

Departure controller
For the DCO, almost all clearances and information exchange can also be sent by CPDLC given the message set. This makes the applications identified in the previous chapter promising. However, due to the tactical nature of the instructions that are provided, current E2E-performance still prevents effective use of CPDLC in the terminal environment. For this reason CPDLC applications are not considered feasible for the Departure Controller within the current timeframe. However, should these limitations be solved, introduction of CPDLC in departure control may well prove feasible in the future.

ACC outbound
All types of information exchange between ACC and the flight crew are potential candidates for CPDLC application, given the nature of the messages included in the services. Looking at E2E performance and the nature of the operation, only less tactical instructions such as directs to waypoints (DCT) outside Amsterdam FIR (e.g. direct OMELO), and the possibility for the flight crew to contact the next ATC centre (ACM service), are considered feasible applications. As for the other functions, the microphone check is a feasible application for ACC as well.

Inbound planning process

ACC inbound
As for ACC outbound, all types of information exchange between ACC and the flight crew could be potential applications, considering the mandated message set. Based on E2E-performance, instructions of less tactical nature, such as communicating EAT, STAR and runway information can be considered potentially beneficial CPDLC applications. When ACC inbound has the opportunity to automate repetitive information that is sent to multiple aircraft, the R/T load could be decreased. In addition, the AMC microphone check, and communication of SSR codes and RVRs are feasible applications. Instructions given for sequencing (such as speed, heading, etc.) are tactical in nature and are at present not considered feasible.

Feeder
Considering the tactical nature of the heading/speed instructions and level clearances, as well as the importance of a prompt TOC, the communications between FDR/ARR and the flight crew are in the current ATM system not deemed feasible CPDLC applications, due to E2E performance. The microphone check is therefore identified as the only feasible application.

Runway controller
Looking at the information exchange between ATC and crew, wind information can be sent by CPDLC. Since this information is supplied simultaneously with the landing clearance, splitting these two types of information (by providing CPDLC free text weather information) would imply additional effort for the RC in sending the information, and for the flight crew in processing inputs from two different channels (R/T and data link) during final approach. Given the importance of the information to the crew, it is preferable to combine both the clearance and important additional information into one message. It can be concluded that in practice no feasible CPDLC application can be identified while arriving flights reside under the responsibility of the RC.

Ground controller
As for departing flights residing under responsibility of GC, no potential CPDLC applications are identified besides the microphone check. The use of the CONTACT and MONITOR instructions as well as other messages that supplement the information exchange between crew and controller is currently still limited, due to required system performance and the significant change in the way of working of the controller.

5.3 Benefits

In summary, when considering the criteria mentioned above, the following applications are considered beneficial for implementation in the time-frame considered in this study:

- AMC microphone check;
- Transfer of communications and DCT functionality for ACC outbound;
- Communicating SSR changes, STAR/RWY information and EAT for ACC.

This section will outline the benefits for each of these feasible applications. In the following paragraph the expected implementation efforts will be discussed.

Microphone check (AMC service)
The use of the AMC service for all ATC units can result in a significant safety benefit. By using CPDLC as secondary means of communication, being independent from R/T, it enables ATC to solve the issue involving microphones blocking a sector frequency or non-com situations. Such functionality does not exist at this moment: if the R/T channel is blocked, there is no alternative possibility to contact flight crews on that frequency to inform them on the issue.

Transfer of communications to next data authority and Direct-To instructions for ACC
Referring to the R/T-load reductions realized by MUAC, Transfer of Communications by CPDLC for ACC is expected to have a significant impact on the R/T-load as well. Swift handling of traffic to UAC could increase controllers' efficiency.

Area Control information exchange
Using CPDLC as a supplementary communications channel for information on EAT, STAR, RUNWAY and SSR changes reduces R/T load. Provided that these routine tasks can occur through CPDLC communication, this may result in a positive effect on capacity and efficiency. The elimination of errors

associated with verbal communication also enhances safety. The ACM service provides an unambiguous and unobtrusive way of communicating the information. For example, no misunderstood numbers or mixing of a flight level value with an instructed heading value.

5.4 Ranking of feasible CPDLC data link applications

Considering the benefits of each application, the following ranking of applications is proposed:

1. ATC microphone check (AMC service) ; offers large safety benefit;
2. TOC and DCT for ACC: widely deployed use will probably result in a significant R/T-load reduction, based on results obtained by MUAC;
3. STAR + transition / EAT / RWY (ACC inbound); fair reduction in R/T load and indirect enhancement of safety.

This ranking is based on the estimated magnitude of the benefits described in paragraph 5.3

5.5 Final remarks

The introduction of CPDLC will allow air traffic controllers to gain experience with a technology that will eventually enable the progression from the current (tactical) way of working towards more plan-based control operations. Such operations are characterised by clearances that encompass longer portions of the flight trajectory, integrating essential phases of flight like the entire descent, and allowing for more flight efficiency and predictability.

The communication of such longer and typically more complex clearances will become increasingly more important. Relevant in this context is the deliberate limitation of the scope of the current EC mandate to not regulate the implementation of integrated data link. A data link system is considered “integrated” when the pilot is able to approve an uplink message and load it automatically in the FMC. This is particularly relevant when considering large uplink messages with long and/or complex clearances. The size and or complexity of such uplinked clearances would be prohibitive for manual entry into the FMC as would be required using the currently mandated CPDLC infrastructure.

The current EC mandate must therefore be considered to constitute an incremental step in the direction towards supporting future concepts. The limitations mentioned will as yet not permit full transition to such operational concepts. It does however facilitate the introduction of data link in the ATC domain, setting the stage for the necessary subsequent evolutions. Thus, CPDLC is also one of the enablers to obtain the desired benefits for airlines: fuel burn and track mile reduction.

Even though CPDLC exchanges cannot yet be used for ATC instructions of a time critical nature, a future mandate may allow for wider application of this communication channel. As all parties involved become more familiar with CPDLC, its usability for other purposes may increase further.

6 Conclusions

To70 was asked to investigate which data link services are beneficial to the Schiphol operation, below FL245, and are implementable in the 2013-2016 timeframe.

The potentially beneficial applications that have been identified in this study result from an analysis of requirements described in the European Data Link Services Implementation Rule (DLS IR) and the EUROCONTROL Data link specification. The DLS IR requires both airspace users and ANSPs in the European airspace to have capability to exchange CPDLC messages via ATN or FANS 1/A. ANSPs will have to be dual stack equipped.

The study for beneficial applications has led to the following conclusions:

- Applications for LVNL controlled airspace that can be considered potentially beneficial within the time frame considered in this study are:
    - The microphone check which is considered to be a feasible application for all ATC / crew communications. It offers a significant safety benefit, since it introduces an additional, independent communications channel for solving blocked sector frequency and non-com issues.
    - Direct-to and transfer-of-communication instructions for outbound and inbound traffic under control of ACC.
    - Planning related information such as STAR + transition / EAT / RWY (ACC inbound); fair reduction in R/T load and indirect enhancement of safety.

- Goal of the EC mandate was to reduce RT load. It can be considered a first step towards use of CPDLC in the operation. CPDLC can be a useful technology to create a supplementary communications channel. By this it enhances safety, enables reduction of RT-load and paves the way towards future concepts. CPDLC is however neither aimed at nor suitable for the complete replacement of the existing RT-channel in high density airspace.

Follow-up study by National Aerospace Laboratory (NLR)

In the study performed by To70, feasible data link applications have been identified and an indication is given of the implementation time of each of the applications. The NLR will identify implementation cost and benefits of each of the applications.

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