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Applying Cognitive Work Analysis to Study Airport Collaborative Decision Making Design

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Abstract— **This paper outlines the usage of a Work Domain Analysis (WDA) for the assessment of operational information requirements for pilots during Airport Collaborative Decision Making (A-CDM). A-CDM presents unique challenges for decision support during dispatch of aircraft and passengers. Decisions by participating airport partners require an understanding of own capabilities as well as the capabilities of participating actors like pilots, air traffic controllers, or other actors involved. While some situations can be pre-planned, decision makers during turn-round operation will always be faced with unanticipated situations resulting from unknown variables in the environment or technological capabilities.**

Work Domain Analysis (WDA) is a technique which allows to model systems by using event-independent representations that can be used to cope with such unanticipated situations. However, to confirm that this technique can be applied usefully, an early validation is required to ascertain that the WDA is relevant to the problem context. This paper presents an approach for confirming a WDA by using pilots as subject matter experts (SMEs) during aircraft turn-round. Firstly, pilots' operational information requirements were identified via an Abstraction-Decomposition Space (ADS) of the A-CDM system developed by the analysis. Then, pilots were asked via a survey to report about events where problems with operational information sharing were encountered during turn-round. Finally, these events experienced by the pilots were mapped through the pilots' information requirements derived from the ADS. The results reveal that pilots' information requirements are not entirely satisfied by current approach to A-CDM and provide confirmation for the usefulness of the WDA to the proposed application as a technique for an A-CDM interface design cycle.

Key words –***abstraction-decomposition space, aircraft turn-round, collaborative decision making, cognitive work analysis, work domain analysis***

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I. INTRODUCTION

Airport Collaborative Decision Making (A-CDM) has been introduced in Europe during field trials at selected airports as a concept which aims at improving air traffic flow and capacity management at airports by improving the communication and information sharing between the various actors at an airport. An airport is considered as *CDM* airport when *A-CDM Information Sharing (ACIS)*, *Turn-Round Process (CTRP)*, and *Variable Taxi Time Calculation (VTTC)* concept elements are applied at the airport [1].

CTRP describes the flight progress from initial planning until take-off by defined '*milestones*' to allow close monitoring of significant events. Flight Update Messages (FUMs) and Departure Planning Information (DPI) are in place to inform all participating CDM partners about the flight progress. Monitoring the flight between the period of milestone 6 (aircraft landed) and milestone 15 (aircraft off-blocks) is a complex task, because situational awareness has to be established across various subsystems of different organizational and operational structures having their own causal and intentional domain constraints. 'Subsystems' here refer to actors who include airport operator, airline company, air traffic control, ground handler, and Central Flow Management Unit (CFMU). Additionally, all terminal and ramp processes have operational interdependencies, e.g. processes can normally not be parallelized, as well as legal requirements, e.g. one side of the aircraft has to be clear of obstructions to ensure that fire fighting access is always possible [2]. In order to increase situational awareness, a number of agreed and trigger events are defined by the A-CDM concept to inform about updates to estimates and/or aircraft turn-round status. A CDM compliance alert will emerge within the Airport CDM Information Sharing Platform (ACISP) in case of disruptions. Any internal or external disruption at these milestones generates an alarm and has to be communicated to all partners in order to maintain situational awareness.

However, while situational awareness can be created through defined A-CDM rules (milestones) and information sharing between subsystems, decision makers are often faced with unanticipated situations where ad hoc decisions are necessary, e.g. missing passenger or incorrect catering. These situations require decision support to all airport partners and actors involved in operational decision making, since the *detail* of operational information which is required for decision making can only be found at *action* level, however operational decisions are usually made at *tactical* level. Action level referrs to the level where flight operation takes place, e.g. airplane, ramp, or airport building; humans executing tasks at this level are referred to as actors, e.g. pilots, ramp agents, or air traffic controllers. But these actors are at various distributed locations and have no access to the ACISP. Therefore communication channels have to be established from action level to tactical level and vice versa to ensure that a *distributed* situational awareness and information sharing can be achieved at *all* levels.

Another reason for the decision making complexity is the responsibility of the flight crews for the safety of the flight. Maintaining safety of the flight can require decision making already during turn-round, e.g. necessary tire/ equipment changes, deloading of unruly passengers or leaving hazardous cargo behind. Such decisions made by flight crews can interfere with the pre-planned work procedures of an aircraft turn-round. Flexible behaviour and problem-solving skills are necessary in order to manage such situations with minimal time effort. Decision support also for such unanticipated situations demands that all affected participants or actors are provided with as complete and flexible decision support models of the situation as possible.

The following chapter will outline the motivation which has led to the development of the research methodology for an analysis of such a problem. Also the research approach will be described and how these initial results are useful to support the overall concept of a Cognitive Work Analysis (CWA) of this ongoing research project with an outlook of the next steps to be done. The research proposal is in accordance with the SESAR IP R&D need of developing, testing, and validating the supporting CDM processes for increased process efficiency and benefits for the ATM network as a whole [7]. Within the SESAR proposed operating principles, A-CDM, System Wide Information Management (SWIM), Network management function in support of User Driven Priorisation (UDPP), and the Total Airport Management (TAM) have been realized as the main enablers to support such airspace/ airport users' requirements [3].

II. MOTIVATION

The A-CDM system has characteristics of decision making in a complex and dynamic environment where decisions often have to be made during unanticipated situations. A single decision can have dramatic effects that propagate rapidly and widely through the air transport system.

During present approach to execution of turn-round processes, time constraints are prevailing and the turn-round process is accomplished aiming at a completion in a Minimum Turn-Round Time (MTTT); However, events which can not be anticipated as mentioned in chapter I, even further increase time constraints on the Target Off Block Time (TOBT); especially if only MTTT is scheduled for the turn-round, boundaries of established turn-round practices are explored. TOBT is the time that an aircraft operator estimates that an aircraft will be ready to start up immediately upon reception of clearance from tower. TOBT predictability is a pre-requisite for ATC to establish a push back/ pre-departure sequence and it is recognized that the main benefits of sharing TOBT are expected in case of disruptions.

Within such environment, the task of a theoretical framework being used must be able to provide a method for analysis, evaluation, and design of a decision support system to aid decision makers during such turn-round operation. E.g. how can required information be determined to display, which format should be used to display information in order to facilitate cooperative working behavior and effective decision making? How should the task be effectively distributed across the humans or automated systems? And at a later stage it should be evaluated how usable and effective the system is which has been developed and whether it leads to enhanced performance.

Cognitive Engineering is an interdisciplinary approach to designing computerized systems intended to support human performance [8]. It is concerned with the analysis, design, and evaluation of complex sociotechnical systems (Andriole & Adelman [9], Rasmussen et al. [10], Woods & Roth [11], and Vicente [12]). The methods of Cognitive Engineering consider workers and the tasks they perform as the central drivers for system design and provide a framework about how people perform cognitive work. Therefore an approach to cognitive engineering is chosen as the concept method for the analysis.

Activity Theory and Distributed Cognition are the foremost theories about cognition. They both show descriptive, rhetorical, inferential power as well as fitness for application and are both predestinate to be applied to the proposed problem context. However, activity theory has the human activity as a fundamental unit of analysis where Distributed Cognition uses an ecological perspective as a central element.

The Distributed Cognition theory seems to be the most promising approach for the analysis of the A-CDM work system, because it can be used to analyze *how* coordination and cooperation of the various subsystems during interdependent work practices are disrupted due to current information representation. While mapping out data/ information/ knowledge and the means of how it is represented, communicated, and adapted during A-CDM, implications can be drawn for the design of information provision in order to support human-human and human-machine interactions. This approach has the potential to identify problems within existing work practices of A-CDM, and has ability to highlight what needs to be attained in a future system design. Most of the other approaches used for human-computer interaction analysis only *describe* settings and systems; Distributed Cognition however approaches the *design* of a system (formative approach).

Another prevailing advantage of Distributed *Cognition* is that the theory can accommodate the rich variety of systems and media inherent in organizations' or groups' cognitive processes like within A-CDM. Since the unit of analysis is not committed to a fixed value, the entire system can be decomposed into the smaller, functional groups. However, Nardi [13] and Rogers [14] argue that analysis towards distributed cognition approach cannot generally be used: a low-level distributed cognition analysis will not enhance engineering practices for building design applications. Also the theoretical perspective is committed to ethnographical data collection: a substantial investment is required to actually apply the theory to any specific issue [15, 16].

A framework for using Distributed Cognition theory which has recently grown in popularity is the *Cognitive Work Analysis*. Originated from the problems faced in nuclear power plant control, Rasmussen [17] has developed the analytical framework of a Cognitive Work Analysis (CWA) as a basis for the design of decision support systems in complex environments. CWA is a conceptual framework that allows analysis of the forces which shape human-information interactions via application of conceptual constructs rather than testing and verification of models and theories [18]. It is work centered rather than user centered and considers people who interact with information as actors involved in their work-related actions, rather than as users of the system. CWA is using a range of methods to analyze the various constraints that are imposed on the activities of a particular system. For the analysis of a system design, it is necessary to understand not only the work actors do, but also their information behavior in context of their work and the reason for their actions. This allows an application to specific situations.

For this reason, CWA was already successfully applied to many other complex domains. The majority of studies on CWA have focused on its application to interface design (e.g. Burns, 2000 [19]; Burns, Bryant & Chalmers, 2000 [20]; Dinadis & Vicente, 1999; Gualtieri, Elm, Potter & Roth, 2001, Naikar, Hopcroft & Moylan, 2005). CWA was also applied to existing systems, e.g. for process control (Vicente 1996; Jamieson & Vicente, 1998), to design interfaces designing teams (e.g. Gualtierir, Roth & Eggleston, 2000; Naikar, Pearce, Drumm & Sanderson, 2003), evaluating design proposals (Naikar & Sanderson, 2001); analyzing training needs (Naikar & Sanderson, 1999; Naikar & Saunders, 2003); and developing specifications (Leveson, 2000).

CWA consists of five stages: Work Domain Analysis WDA (1), Control Task Analysis (2), Strategies Analysis (3), Social Organization and Cooperation Analysis (4), and Worker Competencies Analysis (5). Primary focus of the analysis is originally on the work domain. This first phase of analysis, the WDA, identifies a fundamental set of constraints imposed on the actions of any actor, and develops an event-independent representation that can be used to cope with novel situations. However, a clear distinction between the different types of hierarchical relations within the work system is necessary for a proper WDA [21]. The decomposition (part-whole) hierarchy and an abstraction (means-end) hierarchy together form a two-dimensional Abstraction-Decomposition Space (ADS) which is able to show the generic properties of a complex system. This adds unique value for understanding the system, and the ADS modeling tool is used here to develop a schematic representation of the A-CDM domain. The important feature of an ADS is the *way* it provides a representation of the complex system and also *how* it provides a *basis* for identification of the information actors need in order to deal with unanticipated events.

Problem solving using the ADS can be carried out via identification of constraints by starting at high level of abstraction and then deciding which lower level function is relevant to the current situation. This iterative "zoom-in" supports goal-directed problem solving via a "why, what, or how" questioning. E.g. the present level of observation defines the *what* level, while the level above specifies *why* or the level below the *how*.

However, the greatest value of this framework can be derived from its ability to identify information needs which is required to cope with unanticipated events. Although some researchers argue that it is not possible to identify such information (Mitchell, 1996 [22]; Shepherd, 1993 [23]), Rasmussen [24] disagrees by laying out the rationale of complex systems control requirements imposed by unanticipated events: This leads to the design requirements of information representation for actors' needs during such events.

III. Method

A methodological approach is used for the analysis of the CDM turn-round. Firstly, an ADS is developed by using the step-by-step WDA methodology described by Naikar et al [25]. The ADS is then used to make implications for information requirements of pilots during A-CDM by representing the different categories of required information, based on the ADS summary table (figure 1). However, it has to be confirmed that this technique can be applied usefully and the analysis is relevant: Work domain model based interfaces can also lead to false diagnosis because its validity is initially not based on experimental results (Burns et al [26]; Vicente, Christoffersen & Pereklita [27]; Christoffersen, Hunter & Vicente [28]). To confirm the A-CDM system constraints, the work domain model is compared with the results from a pilot questionnaire on unanticipated events during turn-round which was developed independent from the ADS. Pilots were asked to forward information requirements and current interface design constraints during turn-round situations which were seen as critical for situational awareness in the existing turn-round processes. According to Naikar [25], validation of the ADS should be based on other information than that was used to create the ADS.

The overall objective of the study was to confirm that the ADS model captures the domain constraints during A-CDM seen from pilots' perspective that were used in the turn-round scenarios. If any constraints were missing, the ADS can be improved by adding those constraints. At a later stage of the research, also the constraints identified by all other participating airport partners and actors will be identified via brainstorming sessions and unstructured interviews with SMEs. Constraints other than from work domain itself will be analyzed in the next phases of the CWA.

A. *Work Domain Analysis of the A-CDM System*

A WDA is required to develop an event-independent representation of the work system. Naikar [25] describes a step-by-step methodology for a WDA which is now outlined as applied for the A-CDM system. The following steps were executed in order to develop the ADS.

Step 1: Establish the purpose of the WDA

This step involves defining the purpose of the analysis. It includes two parts which are *defining* the problem and defining *how* WDA will be used to address the problem [25]. For the analysis, two main purposes were identified which are the identification of the information requirements of all operators during turn-round in order to maintain turn-round process predictability, and identification of the underlying airport infrastructure necessary to support these requirements. The WDA is used for developing a functional model of A-CDM system from the viewpoint of an actor: it should be able to identify the different categories of information which decision makers require, and the airport infrastructure that might be required to *support* decision making during A-CDM. In the next steps of the research project, also other actors' and airport partners' viewpoints will be captured.

Step2: Identify Project Constraints

Not only the purpose, but also the *constraints* that may affect *how* the WDA is conducted have to be identified in order to maintain the pursued scope and focus of the analysis. For this research on A-CDM, the main constraints emerged from complexity of the problem environment, time & expertise related constraints. The scope of the analysis depended heavily on the information made available by participating stakeholders.

Step 3: Determine the Boundaries of the WDA

The analyzed work system can be defined as the processes necessary to maintain situational awareness during turn-round in order to achieve a reliable TOBT. During this step, human-human or human-computer interactions related to operational information sharing processes are reviewed in regard of the aim to make the TOBT as predictable as possible between milestones 6 and 15. This artificial boundary was chosen in order to keep the WDA in a useful and obtainable scope. Nevertheless there are numerous elements *outside* the focus system which influence elements *within* the focus of the analysis, e.g. weather, legal requirements, but for practical considerations they will be left outside of the analysis.

Step 4: Identify the Nature of Constraints

According to Naikar [25], it is necessary to identify the location of the focus system on the causal-intentional continuum, because the *nature of* the constraints that should be modeled in the ADS has to be found (Hajdukiewicz [29]). The categories defined by Rasmussen [17] are used as a basis to determine the nature of the constraints of the proposed problem space. It was concluded that A-CDM has major attributes to a system governed by actors' intentions and the nature of constraints modeled by the WDA are *intentional* constraints based on organizational policies, legislation, and other forms of regulation, social laws and conventions, and actors' intentions or motives. This goes along with the identified purpose of the WDA.

Step 5: Identify Potential Source of Information

For construction of an ADS, the potential sources of information have to be identified [25]. A large number of data/ information sources were found that could inform the A-CDM system domain. This is due to the large number of different participating operators in this system including the airport representatives, airline companies, flight crews, air traffic control, technicians, ramp agents, loaders, airport & ramp personnel, Central Flow Management Unit and passengers. One major information source are documents relating to legislation and company policies, training manuals, airport infrastructure, company reports, and the A-CDM generic procedures.

The work setting itself was used as the second source of information gathering, where observations of work settings were made with minimal interruptions of the observed activities. Observed items include tools and interactions that workers use. Hajdukiewicz [30] recommends distinguishing between *exploratory* observations for understanding the work environment, and *focused* observations concentrated on particular aspects of a chosen system that should be made. Initially only exploratory observations were made for this first stage of analysis.

Additionally, also focus group meetings, observation, brainstorming, and interviews with pilots as SMEs contributed to information gathering. Additional data was also gathered via talkthroughs, and tabletop analyses. For this phase of research, Rasmussen [17] points out that the analyzer should keep in mind the danger that real constraints and actual reasons of behavior are often hidden behind routines and rationalizations, and regardless of the source of information the analyzer should bear in mind the constraints that shape the behavior.

Step 6: Construct ADS- First Iteration

For a first iteration of an ADS, Naikar [25] outlines five phases of developing the ADS which are:

- Identification of Work-Domain Properties
- Defining the Levels of Abstraction and Decomposition
- Developing a Sketch of the ADS
- Evaluating which Cells of the ADS to Populate, and
- Population of Selected Cells of the ADS.

IV. RESULTS

As a first result of following Naikar's step-by-step methodology, a matrix was developed which populates all cells based on the identified work-domain properties, levels of abstraction, and levels of decomposition (table 1). This matrix describes a conceptual view of the A-CDM system and offers a conceptual level of resolution for viewing the A-CDM work domain. The conceptual view of the A-CDM proposed here offered by the three cells at the purpose-related functions level of abstraction is that of the possible functions of the A-CDM system. The three cells offer different resolutions for viewing the functions of the A-CDM which are the functions of the whole A-CDM Decision Making system, the functions of the CDM Turn-Round Element, and the functions of the different components of A-CDM like the milestones, ACISP, and A-CDM Partners (Fig 1).

	Total System Airport Collaborative Decision	**Sub-System** CDM Turn-round Process Element	**Component** Milestones, ACISP, A-CDM Partners
Functional Purpose	*Purposes* ■ Improve work together at an operational level ■ Efficient and safe daily flight operation with reliable information provision & Common Situational Awareness *External Constraints* ■ Laws & Regulations by airport, national government, Europe, IATA, EUROCONTROL, ICAO ■ Local Standard Operationg Procedures	*Purposes* ■ Provide the A-CDM partners with a common situational awareness ■ Anticipation of disruptions & expeditious recovery through information sharing among all partners including passengers *External constraints* ■ Distributed location between CDM partners and actors ■ Laws & Regulations	*Purposes* ■ Milestones: To provide decision makers with information about flight progress and trigger decision making ■ ACISP: To provide information sharing between the Airport CDM Partners ■ A-CDM Partner Goals *External Constraints* ■ No & design of Milestones, Alert
Abstract Function	*Criteria* ■ ATTT ■ Turn-round compliance (STTT vs ATTT) ■ TOBT/TSAT Predictability ■ EIBT Predictability: EIBT vs time ■ Ready Reaction Time: AOBT - ARDT	*Criteria* ■ ATTT ■ Turn-round compliance (STTT vs ATTT) ■ TOBT/TSAT Predictability ■ EIBT Predictability: EIBT vs time ■ Ready Reaction Time: AOBT – ARDT	*Milestones* ■ CDM Procedure Group Meetings ■ Performance Assessments *ACISP & A-CDM Partners* ■ User feedback & Performance Assessment
Generalised Function	■ Safe & efficient usage of available resources ■ Effective law, regualation, procedure, and policy enforcement ■ Redesign of airport operational procedures ■ Implementation of CDM functions	■ Safe & efficient turn-round & flight ■ Adherence to CDM procedures ■ Efficient implementation of collaborative decisions at action level ■ Enforcement of laws, regulations, procedures	*Milestones* ■ Data/ Information availability & Practicability of Information *ACISP & A-CDM Partners* ■ Physical dynamics of user behaviour
Physical Function	■ Provision of reliable information for all CDM partners ■ Collaborative operational decision making ■ Increasing Situational Awareness ■ A-CDM Information Sharing Platform (ACISP)	■ Efficient information provision & cooperation between operators & actors ■ Distributed Situational Awareness at action level ■ Efficient command & control structure between pretactical & action level of operation	*Milestones* ■ Functionalability/capability/limitations & status ■ Inform all partners *ACISP & A-CDM Partners* ■Functionalability/capability/limitation ■ Establish Situational Awareness
Physical Form	■ IT platforms with operational information sources, e.g. TOBT/ TSAT ■ AMAN/DMAN ■ Airport Operation Centre (APOC) ■ Representative Decision Makers of all partners ■ Meteorlogical features, e.g. adverse weather condition	■ Printed Information/ Data about TOBT/TSAT ■ Information Screens for passengers ■ Airport Infrastructure & Airspace Structure ■ Alert Messages to all CDM partners via the ACISP ■ Flight Update Messages (FUMs)	■ Electronic Data/ Information ■ Software Applications ■ HMIs, e.g. ACARS, Telefon, computer ■ Computer Network ■ Operation Room ■ Passengers ■ Actors

Figure 1. A-CDM Conceptual Matrix

Step 7: Construct ADS- Second Iteration

For the second iteration of the ADS, additional information sources were used to further develop the ADS. Therefore, the following phases were again carried out:

- Focused Field Observations
- Walkthroughs and Talkthroughs
- Interviews
- Table-Top Analysis

The resulting ADS (Figure 2) involved reviewing the ADS with domain experts who agreed on the variouselements of the ADS model including the levels of abstraction and means-ends relations in the ADS, the level of decomposition and part-whole relations in the ADS, and the categories of constraints in each cell of the ADS.

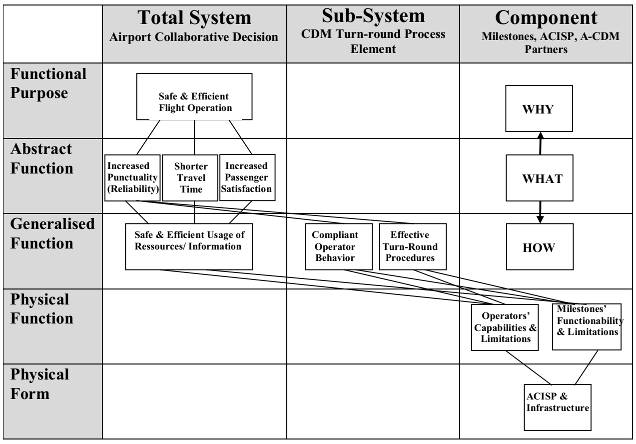

Figure 2. A-CDM Abstraction-Decomposition Space

A. Pilots' Decision Support

The next step was to draw implications from the ADS for possible information provision to pilots and pilots´ support for decision making during turn-round. These identified information requirements will later be mapped against the results from the cockpit survey in order to confirm that the WDA is on the right track and the ADS is valid.

Implications are divided in two main areas which are:

1. Pilots' Information Requirements

Information requirements identified by the ADS include data which should be provided to pilots to increase situational awareness at the distributed location of the cockpit. Failing to present required data, presenting data in an inappropriate manner or presenting too much data can potentially have detrimental effect upon task performance (Salmon et al [31]). These information requirements can then be used to inform the A-CDM design by specifying what data should be presented to the cockpit via available communication devices like ACARS, phone, or two-way radio. E.g. Salmon et al [32] has used the ADS to specify information requirements for a command and control knowledge wall display, or Ahlstrom [33] used the ADS for determining the types of information that air traffic controllers require for effective performance during adverse weather conditions. Therefore it is argued that the ADS of the A-CDM system can be used to identify different categories of information that pilots require to support effective decision making during turn-round.

Information requirements are extracted from the ADS of A-CDM as they relate to purpose related functions of cockpit information requirements. (Figure 3)

	Total System Airport Collaborative Decision	**Sub-System** CDM Turn-round Process Element	**Component** Milestones, ACISP, A-CDM Partners
Functional Purpose	■ A-CDM Information Sharing, e.g. TOBT, TSAT ■ Common Situational Awareness		■ Pilots`Goals ■ Safety Level ■ Airport Performance ■ Aircraft Technical Status ■ A-CDM Partner Goals
Abstract Function	■ ETTT ■ Turn-round compliance of Actors involved ■ TOBT/TSAT/TTOT/CTOT Creation ■ EIBT Predictability: EIBT vs proposed waiting time	■ Milestones 6 until milestone 15 ■ Not time & time related data ■ Aircraft operational statu ■ Variable Taxi Time Calculation ■ CDM Complicance Alarms	■ Economic Cost of Planned/ Alternative Turn-Round ■ Safety Level ■ Performance and Status of All Participating ■ Aircraft Requirements & Status
Generalised Function	■ Airport Apron Rules & Regulations ■ Warnings, e.g. airport policies & local restrictions ■ Behavioral recommendations, e.g. taxi time required,	■ TIBT & Stand Information ■ Ground Handling Start Delay ■ Runway in use ■ EOBT/TOBT/CTOT Complicance alarms ■ EXOT	■ Physical turn-round control task support ■ Cognitive turn-round control task support ■ Turn-Round Complicance control
Physical Function	■ Operational Information Sharing with Cockpit ■ CDM operating procedures ■ Information Sharing among particpating actors ■ A-CDM Information Sharing Platform (ACISP)	■ Information about Changes of TIBT & Stand ■ Information about Ground Handling Start Problems ■ Information about Runway changes ■ Information about EOBT/TOBT/CTOT changes ■ Information about scheduled EXOT, if relevant	■ Capability/ Knowledge Level of All Participating ■ Availability of Resources ■ Current task status in relation to goals
Physical Form	■ Access to ACISP from cockpit ■ Provision of TOBT/TSAT/TTOT to cockpit ■ Information about Passenger Boarding Time ■ Environmental Condition Information ■ Turn-Round disruptions		■ Current Component Performance & Status ■ Current Airport & Aircraft Condition ■ Other A-CDM users location & future movements

Figure 3. Pilots Information Requirements during Turn-Round

The information requirements can be grouped in categories which are not available to pilots in current A-CDM approach:

- A-CDM Information Sharing elements, e.g. TTOT, EXOT
- A-CDM compliance alarms
- Airport warnings & recommendations
- Operational status information including disruptions and other actors' goals
- Participating actors' performance, status, and knowledge level
- Availability of resources

2. Possible Support for Pilots

The ADS reveals also information which could support pilots in decision making during turn-round, if it would be made available to cockpits. This includes:

- Understanding of A-CDM generic procedures (e.g. DPI or FUMs)
- Understanding of the integration within traffic of other aircraft (e.g. pre-departure sequence)
- Physical turn-round compliance control task support
- Ensuring of awareness & knowledge level of other participating actors

Table 1 shows the information that should be provided to support pilots for safe, efficient, and reliable turn-round procedures as identified by the ADS. This table compares the information which is already given to pilots and the information which is required by them according the ADS. It is also taken into account, if the information given complies with *all* information requirements or only *partially*.

Table 1 Information for Pilots' Decision Support

Information Requirement	Information Provided to Pilots		
	YES	NO	PARTIALLY
Information from ACISP		x	
TOBT/ TSAT	x		
ETTT		x	
Turn-Round Compliance of other actors		x	
CTOT	x		
TTOT		x	
Apron Rules & Regulations	x		
Infrastructure related warnings			x
Behavioral Recommendations		x	
Operational Information			x
CDM Operating Procedures	x		
Information Sharing among participating actors			x
Passenger Boarding Time		x	
Environmental Condition Information	x		
Turn-Round Disruptions		x	
Time related Data			x
Not time related Data	x		
Aircraft Operational Status	x		
Variable Taxi Time Calculation		x	
CDM Compliance Alerts		x	
Target In Block Time		x	
Stand Information	x		
Ground Handling Start Delay		x	
Runway in Use	x		
EOBT/TOBT/CTOT Compliance alarms		x	
EXOT		x	
Pilots`Goals	x		
Safety Level		x	
Airport Performance		x	
Aircraft Technical Status	x		
A-CDM Partner Goals		x	
Economic Cost of planned/ alternative Turn-Round			x
Performance & Status of all participating actors		x	
Aircraft Requirements & Status	x		
Physical turn-round control task support			x
Cognitive turn-round control task support		x	
Turn-Round Compliance control task support		x	
Capability/ Knowledge Level of all participating actors		x	
Available Resources		x	
Current task status in relation to goals		x	
Current component performance & status		x	
Current airport & aircraft condition			x
Other A-CDM users location & future movements		x	

Focus has not yet applied on provision of such information to the cockpit or *how* it should be provided. It is argued however that availability of this information could contribute to a distributed situational awareness while improving turn-round efficiency.

B. *Validation of the ADS*

This step aims to determine whether the ADS is as accurate and complete as possible. Naikar [25] proposes a number of possibilities for the validation of ADS. One possibility is to use the material already studied for the construction of the ADS, however it is not necessarily useful to use the same sources of information for validating the ADS.

A better option is to use reasoning patterns of actors in various situations, e.g. incident reports with necessary decision making (Naikar, 2005). For this reason, the pilot survey was developed aiming at reconstructing such situations which pilots encountered during turn-round. The situations proposed in the survey were all concerning turn-round process reliability and required cooperation and awareness of various actors or airport partners similar to the A-CDM Turn-Round concept element, however seen only from pilots' perspective. A large number of situations critical for TOBT adherence were proposed to the pilots; nevertheless pilots were allowed to add also other routine or novel events which they encountered.

Thereafter, the collected data was analyzed and examined for work-domain properties that characterized actors' reasoning patterns during these turn-round situations. The work-domain property data were then mapped in form of examples onto the ADS and examined as to whether the situations are captured by the different categories of constraints, and analyzed which parts of the decomposition space that are represented in the ADS, were involved.

C. The Design of the Cockpit Survey

The cockpit survey examined five different turn-round operation situations which entail the risk to jeopardize flight punctuality by delayed turn-round processes due to problems with information-interactions between aircraft cockpit and decision makers like airport partners at operation center or actors at the ramp. The ADS developed by the WDA provided some insights for understanding the cockpit's information requirements during turn-round. However, the analysis is not validated through experimental results.

The aim of the questionnaire was therefore to capture pilots' view on non-cooperative information-interaction behavior between pilots and other airport partners or actors, and the possible reasons and consequences of such behavior. Cooperative behavior is seen as a synchronous and homogeneous sharing of required information for operational decision making or situational awareness among participating actors. This should enable the pilots and all airport partners or actors involved to respond to the local context in real time.

Hence, the survey addressed how the airport information sharing process was influenced by the following variables:

- Interaction Mode (synchronous versus asynchronous)
- Information Distribution (homogenous versus heterogenous)

The result should then allow deducting information requirements for achieving distributed situational awareness of the pilots during these situations. Pilots were asked to report recent experiences on failed sharing of operational information and the consequences on the process delay. They were also asked whether a departure delay was encountered after the delayed turn-round process.

The turn-round situations were grouped into three categories:

- Information provision from other actors to cockpit during flight
- Information provision from other actors to cockpit during turn-round
- Information provision from cockpit to other participating actors

The survey was conducted on-line for a period of two months with invitations to pilots from many European airlines.

Table 2 provides an overview of the different turn-round operation situations and the categories of questions which were asked together with each of these situations:

Table 2: Turn-Round Situations

TURN-ROUND	(NON-) COOPERATION/	COOPERATIVE COMPONENT	AIRPORT	FREQUENCY	RELEVANCE
Gate Assignment	Y/N	Aims/Resources/ Abilities	Hub/ Non Hub	Daily/Weekly /Monthly/ Irregularly	Avoidable Delay Likelihood
Ground Handling/ Ramp Delay	Y/N	Aims/Resources/ Abilities	Hub/ Non Hub	Daily/Weekly /Monthly	Avoidable Delay Likelihood
ATC Related Delay	Y/N	Aims/Resources/ Abilities	Hub/ Non Hub	Daily/Weekly/ Monthly	Avoidable Delay Likelihood
Operational Info OUT Related Delay	Y/N	Aims/Resources/ Abilities	Hub/ Non Hub	Daily/Weekly /Monthly	Avoidable Delay Likelihood
Operational Info IN Related Delay	Y/N	Aims/Resources/ Abilities	Hub/ Non Hub	Daily/Weekly/ Monthly	Avoidable Delay Likelihood

Approach of the Survey

The pursued approach had the aim to lay out the broadest range of possible turn-round situations in order to cover as many situations as possible. Accomplished brainstorming sessions with pilots revealed that information sharing problems during turn-round can be manifold and that each event can potentially be unique in its specific situation. However, a number of problems occur regularly and can potentially be attributed to a specific category of problem. Therefore, the questionnaire proposed to the pilots included various situations with all CDM partners and actors involved in operational information sharing. These are the airport operator, air traffic control, CFMU, airline company, ground handler, ramp agent, flight manager, check-in and boarding personnel, loaders for cargo, mail and baggage, and service providers like fueling, catering, cleaning.

Table 3 Possible Information-Interactions during Turn-Round

Turn-Round Problem	Information Required
Availibility of Parking Stand	Expected Delay /Reason of Delay for Parking
Baggage Loading/ Unloading	Delay: Expected duration, reason, No of baggage
Ramp Transfer Bus (Passenger or Crew)	Delay: Expected duration, reason
Catering	Delay: Expected duration, reason
Cleaning	Delay: Expected duration, reason
Fueling	Delay: Expected duration, reason
Check-In	Delay: Expected duration, reason
Security	Delay: Expected duration, reason
Boarding	Delay: Expected duration, reason
Airport Facilities	Delay: Expected duration, reason
Wheelchair-boarding	Delay: Expected duration, reason
UM Boarding	Delay: Expected duration, reason
Special Loading (e.g. musical instrument)	Delay: Expected duration, reason
VIP Boarding	Delay: Expected duration, reason
ATC Request	Delay: Expected duration, reason
CFMU Regulation	Delay: Expected duration, reason
Aircraft Change	Reason and status of new aircraft
Technical Repair	Reason and expected l duration of repair
Crew Duty Change (new duty roster)	Timely Provision
Crew Change (new crew member)	Timely Provision
Crew Proposal: Connecting Passenger	Response and expected action
Crew Proposal: Necessary A/C repair	Response and expected action
Crew Proposal: Avoidance of A/C Change	Response and expected action
Other: No Flight documents delivered	Response and expected delivery
Other: No Ramp Agent available	Status of Service Delivery
Crew Proposal: Avoidance of A/C Change	Response and expected action

Pilots were asked to choose their agreement between two statements entailing information provision for each of the information problems from table 3:

- I was informed about the problem in time (includes possibility to take appropriate action)
- I learned about the problem having observed that the process was not executed or I received information too late.

For each turn-round situation of the survey, the pilots were asked to rate on a scale from 1 = very unlikely to 4 = very likely, whether the delay of the turn-round process was avoidable or not.

Additionally, the pilots were asked to assess *how many minutes* of delay resulted from the turn-round process which was deviating from established turn-round schedule, and how many minutes *departure* delay were encountered *after that* turn-round with this service failure. Only events were taken into account which were reported to occur at least on a monthly basis.

The ADS reveals also a pilots' information need about '*task status in relation to goals'* derived from the physical function of the A-CDM Partners component. Therefore, the pilots were also asked to attribute the possible reason for the problem causes analogous a cooperation model of Ferber [34]. The reasons are divided into three categories which are the

- Aims
- Resources, and
- Abilities

The level of agreement to each of the three categories was measured with 1 = very unlikely to 4 = very likely. This data will at later stage also be used to identify non-cooperative situations according to Ferbers' Cooperation Model.

In all questions, multiple and equivalent choices were allowed, that means the pilots could assign multiple causes of failures to each specific event.

Survey Data Analysis

For the data analysis, only situations were chosen where pilots reported an information-interaction problem has taken place which has an impact on ground handling or on other service delivery during turn-round. They were organized as follows:

- The situations reported by pilots are summarized in a table, displaying the number of occurrences.
- *Descriptive data analysis* was used to obtain measures of central tendency or dispersion about the avoidability of delay via Likert scale. It was discovered that some situations were more avoidable than others.
- Delay of the service delivery was reported to be different for different situations.
- Correlation analysis was carried out between turn-round process delay and departure delay.

Statistical Analysis was performed with SPSS 17.0 and Excel. An α level of 0.5 was chosen as decision criterion. Spearman's rho was used as a measure of correlation.

Survey Results

1. Pilots' General Information

The 196 pilots participated in the survey with useful results (n=106) from for airlines like Austrian (n=2), Air Berlin (n=16), Air France (n=9), Easy Jet (n=1), Lufthansa (n=77), and Transavia (n=1). 44.6% of the pilots were captains, 55.4% first officers. Average experience was reported by 6.58 years as First Officer and 7.37 years as Captain.

2. Pilots' Information Requirements from Survey

In this section, the results concerning information requirements will be shown as a function of avoidability of delay like reported by pilots. Figure 4 shows the mean values that received high ratings of the five proposed turn-round situations:

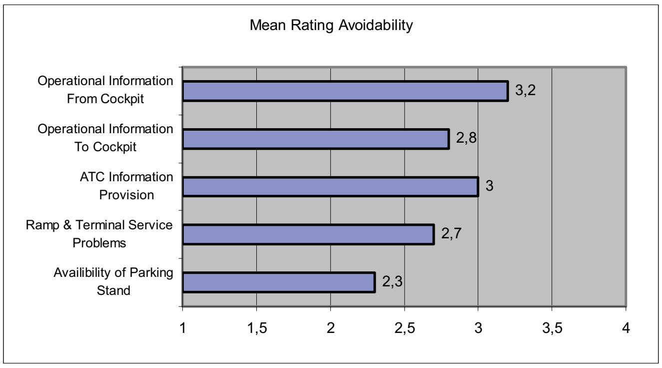

Figure 4 Mean Rating Avoidability of Delay

The highest rating received by the pilots was the need to take into account operational information given by pilots, where the pilots see fewer options to avoid delays through timely notification of parking stand availability.

Pilots were asked to report events they experienced, however, most of the pilots used the *proposed* situations which were verified as critical turn-round events during focus group meetings. Figure 5 shows reported frequency of the five proposed turn-round situations of all participating pilots and reported turn-round events as frequency in percent in the order of the survey.

Turn-Round Problem	Reported Situation Frequency in %	Reported Event Frequency in %
Availability of Parking Stand	95,1	95,1
Baggage Loading/ Unloading	100	47,1
Ramp Transfer Bus (Passenger or Crew)	100	11,8
Catering	100	1
Cleaning	100	2,9
Fueling	100	4,9
Check-In	100	1
Security	100	2
Boarding	100	13,7
Airport Facilities	100	4,9
Wheelcharboarding	100	3,3
UM Boarding	100	0
Special Loading (e.g. musical instrument)	100	1
VIP Boarding	100	5,9
Missing Flight Documents	100	2
ATC Request	95,1	99
Aircraft Change	95,1	63,1
Crew Duty Change (new duty roster)	95,1	18,4
Crew Change (new crew member)	95,1	1,9
Technical Repair	95,1	7,8
Other	95,1	3,9
Crew Proposal: Connecting Passenger	93,2	5,8
Crew Proposal: Necessary A/C repair	93,2	33
Crew Proposal: Avoidance of A/C Change	93,2	47,5
Crew Other Proposal	93,2	5,8

Figure 5 Turn-Round Events reported by pilots

3. Effect of Process Delay on Departure Punctuality

A statistically significant correlation could be identified for the turn-round processes which produced a delay (independent variable) in relation to the departure delay after turn-round as shown in percent of of all reported information sharing failures (dependent variable). Following figures show the proposed situations like late parking stand assignments (figure 6), ramp & terminal service delivery (figure 7), operational information sharing *to* cockpit (figure 8), and operational information sharing *from* cockpit (figure 9):

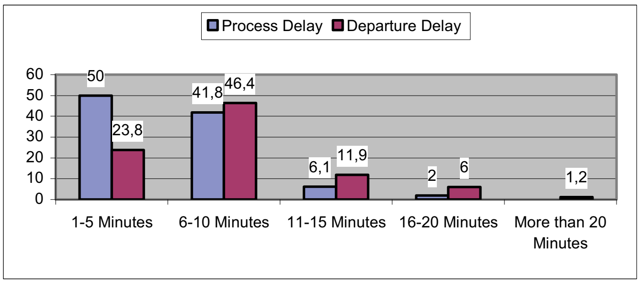

Figure 6 Process & Departure Delay for Parking Stand Assignment

(Spearman's rho = 0.363, p=0.001, two tailed test, N=84)

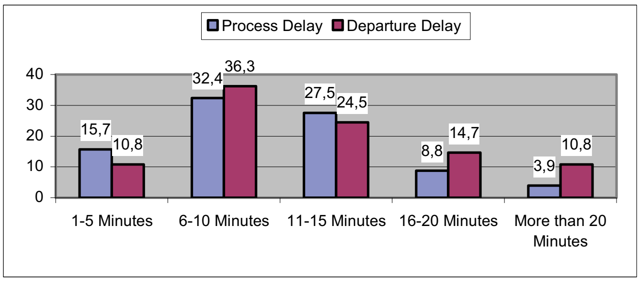

Figure 7 Ramp & Terminal Service Delivery

(Spearman's rho = 0.424, p=0.000, two tailed test, N=102)

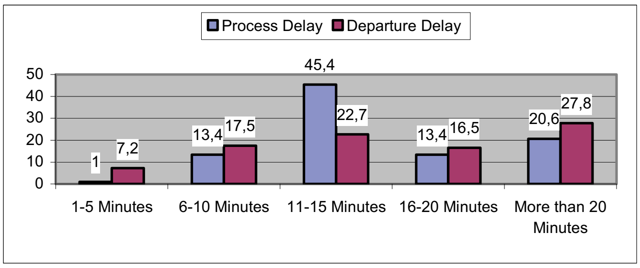

Figure 8 Operational Information to Cockpit

(Spearman's rho = 0.760, p=0.000, two tailed test, N=97)

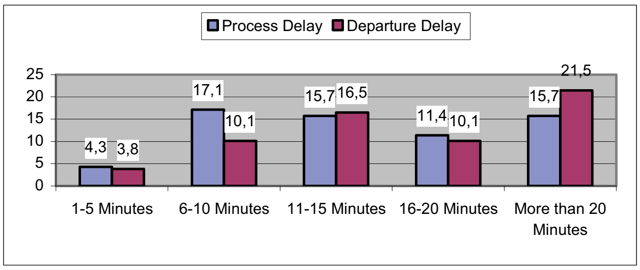

Figure 9 Operational Information From Cockpit

(Spearman's rho = 0.854, p=0.000, two tailed test, N=79)

Even though it is not possible to infer that the turn-round process delay can be merely contributed to the overall departure delay, it entails a high risk of being responsible for the delay since also the *amount* of delay correlates significantly between process delay and departure delay. It can be argued that this result is only pilots' assessments and not real data during turn-round. However, in all situations pilots are always directly affected by the delay and physically present where the turn-round takes place.

4. Current Task Status in Relation to Actors' Goals

Following table provides the pilots' assessment of possible failure causes expressed in three components like aims, resources, and abilities. Even though it can be questioned that it is possible for pilots to identify failure causes objectively, it is argued that pilots have operational experience from a home base airport which they are familiar with. Since all participating pilots fly for airlines having a large network, pilots can easy compare turn-round services from other airports with their home base. This allows a unique way to compare service provision of various airports. Figure 10 compares the different assigned ratings of the three components aims, resources, and abilities:

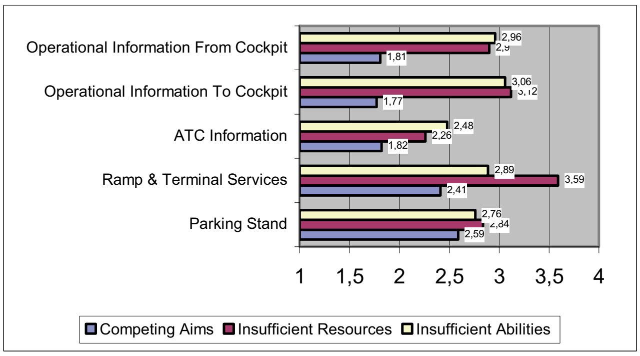

Figure 10 Possible Information Sharing Failure Causes

V. MAPPING SURVEY RESULTS ON THE ADS

The events experienced by the pilots were mapped through the pilots' information requirements derived from the ADS, and the relevant areas identified and highlighted. The particular information gained from the pilots' survey followed the same functional relations as the ADS identified by the analysis. Figure 11 shows the specific information requirements during turn-round service processes as reported by the pilots:

	Total System Airport Collaborative Decision	**Sub-System** CDM Turn-round Process Element	**Component** Milestones, ACISP, A-CDM Partners
Functional Purpose	■ A-CDM Information Sharing ■ Common Situational Awareness		■ Pilots`Goals ■ Safety Level ■ Airport Performance ■ Aircraft Technical Status ■ A-CDM Partner Goals
Abstract Function	■ ETTT ■ Turn-round compliance of Actors involved	■ Milestones 6 until milestone 15 ■ Not time & time related data ■ Aircraft operational statu ■ Variable Taxi Time Calculation ■ CDM Complicance Alarms	■ Economic Cost of Planned/ Alternative Turn-Round ■ Safety Level ■ Performance and Status of All Participating ■ Aircraft Requirements & Status
Generalised Function	■ Airport Apron Rules & Regulations ■ Warnings, e.g. airport policies & local restrictions ■ Behavioral recommendations, e.g. taxi time required	■ TIBT & Stand Information ■ Ground Handling Start Delay	■ Capability/ Knowledge Level of All Participating ■ Availibility of Ressources
Physical Function	■ Operational Information Sharing with Cockpit ■ CDM operating procedures ■ Information Sharing among particpating actors ■ A-CDM Information Sharing Platform (ACISP)	■ Information about Changes of TIBT & Stand ■ Information about Ground Handling Start Problems ■ Information about Runway changes ■ Information about EOBT/TOBT/CTOT changes ■ Information about scheduled EXOT, if relevant	■ Current Component Performance & Status ■ Current Aircraft & Airport Condition ■ Other A-CDM users' location & future movements
Physical Form	■ Access to ACISP from cockpit ■ Provision of TOBT/TSAT/TTOT to cockpit ■ Information about Passenger Boarding Time ■ Environmental Condition Information ■ Turn-Round disruptions		■ Current Component Performance & Status ■ Current Airport & Aircraft Condition ■ Other A-CDM users location & future movements

Figure 11 Mapping of Service Information Requirements on ADS

It can be seen from figure 11 that although actors like pilots are not inherent A-CDM Partners, the low level details of information about the capability/ knowledge level of all participating at physical function level can be traced back to the overall purpose of A-CDM Information Sharing. Also the physical form of the identified components which reveals a need for the current component performance and status, can affect other CDM related processes in a dynamic way as shown by the other active highlighted areas of the ADS. Therefore it is argued that sufficient situational awareness should be distributed among airport partners *and* actors involved and not solely established among airport partners only.

Other problems were reported as caused by non-information sharing of ATC: Because information about a runway change is not communicated to the pilots, cockpit needs extra time for changing take-off performance calculations *after* clearance request and this entails the risk of jeopardizing TOBT and TTOT adherence. Short notices of runway changes can also significantly change taxi times with additional risk of missing CTOT. Figure 12 shows the specific information requirements for such situations as identified from ADS.

	Total System Airport Collaborative Decision	**Sub-System** CDM Turn-round Process Element	**Component** Milestones, ACISP, A-CDM Partners
Functional Purpose	■ A-CDM Information Sharing ■ Common Situational Awareness		■ Pilots`Goals ■ Safety Level ■ Airport Performance ■ Aircraft Technical Status ■ A-CDM Partner Goals
Abstract Function	■ ETTT ■ TTOT Creation	■ Milestones 6 until milestone 15 ■ Not time & time related data ■ Aircraft operational statu ■ Variable Taxi Time Calculation ■ CDM Complicance Alarms	■ Economic Cost of Planned/ Alternative Turn-Round ■ Safety Level ■ Performance and Status of All Participating ■ Aircraft Requirements & Status
Generalised Function	■ Airport Apron Rules & Regulations ■ Warnings, e.g. airport policies & local restrictions ■ Behavioral recommendations, e.g. taxi time required	■ Runway in Use ■ EXOT	■ Capability/ Knowledge Level of All Participating ■ Availibility of Ressources
Physical Function	■ Operational Information Sharing with Cockpit ■ CDM operating procedures ■ Information Sharing among particpating actors ■ A-CDM Information Sharing Platform (ACISP)	■ Information about Changes of TIBT & Stand ■ Information about Ground Handling Start Problems ■ Information about Runway changes ■ Information about EOBT/TOBT/CTOT changes ■ Information about scheduled EXOT, if relevant	■ Capability/ Knowledge Level of All Participating ■ Availability of Ressources ■ Current Task Status in Relation to Goal
Physical Form	■ Access to ACISP from cockpit ■ Provision of TOBT/TSAT/TTOT to cockpit ■ Information about Passenger Boarding Time ■ Environmental Condition Information ■ Turn-Round disruptions		■ Current Airport & Aircraft Condition ■ Other A-CDM users location & future movements

Figure 12 Mapping of ATC Information Requirements on the ADS

This change in use of runway at physical level depends on knowledge level of all participating and in case of a CTOT regulated flight also estimated taxi out time. Changing the runway without prior notice affects pre-plannned ATTT, however adherence to it is necessary for a reliable sequence planning at the airport. Even figure 7 shows only *pilots'* information requirements, a not communicated runway change will also affect other A-CDM partners and the environment as well.

These two examples give only a snapshot of the overall information requirements from pilots during A-CDM. The other proposed situations follow a similar pattern through the ADS. However it could be confirmed that all information requirements reported via the survey could be identified by using the ADS.

VI. Conclusion

The CWA has confirmed its usefullness for application to the A-CDM work system for several reasons: via an ADS it allows to derive domain constraints and operational information requirements of pilots which could be verified by the results of a cockpit survey. This encourages its further application to identify also information requirements of other participating actors. It cannot be claimed that the ADS is able to cover *all* sytem constraints, however evidence could be given that a numerous operational information which are required by pilot are not yet accessible to them.

A. Abbreviations and Acronyms

ADS	Abstraction-Decomposition Space
A-CDM	Airport Collaborative Decision Making
ACIS	Airport CDM Information Sharing
ACISP	Airport CDM Information Sharing Platform
AOP	Airport Operation Plan
ATC	Air Traffic Control
ATTT	Actual Take of Time
CTOT	Calculated Take Off Time
CTRP	CDM Turn Round Process
CWA	Cognitive Work Analysis
DPI	Departure Planning Information
ETTT	Estimated Turn Round Time
EXOT	Estimated Taxi Out Time
FUM	Flight Update Messages
MTTT	Minimum Turn-Round Time
TAM	Total Airport Management
TOBT	Target Off Block Time
TSAT	Target Start-Up Approval Time
TTOT	Target Take Off Time
VTTC	Variable Taxi Time Calculation
WDA	Work Domain Analysis

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REFERENCES

[1] EUROCONTROL Doc. (2006). *Airport CDM Implementation*, EUROCONTROL, Brussels, Belgium

[2] Fricke, M. & Schultz, M. (2008). *"Improving Aricraft Turn Around Reliability"* in Third International Conference on Research in Air Transportation, Vairfax VA

[3] EUROCONTROL Doc. (2008). *Episode 3*, EUROCONTROL, Brussels, Belgium, unpublished

[4] DLR & EUROCONTROL Doc., (2006). *Total Airport Management*, DLR, Braunschweig, Germany

[5] EUROCONTROL Doc., (2007). ATM Operational Concept: *Concept of Operation for the Year 2011,* EUROCONTROL, Brussels, Belgium

[6] Cockburn, A. (2000). *Writing Effective Use Cases*, Addison-Wesley, Pearson Education, Indiana ID

[7] EUROCONTROL Doc., (2008). *SESAR The ATM Deployment Sequence D4*, EUROCONTROL, Brussels, Belgium

[8] Roth, E.M. & Pew, R.W. (2008). "Integrating Cognitive Engineering in the Systems Engineering Process: Opportunities, Challenges, and Emerging Approaches**",** *Journal of Cognitive Engineering and Decision Making*, pp. 161-164(4), Santa Monica, CA

[9] Rasmussen,J., Pejtersen, A.M & Goodstein, L.P. , (1994). *Cognitive Systems Engineering*, pp.157-175., Wiley, New York NY

[10] Andriole, S.J. & Adelman, L. (1995). *Cognitive Systems Engineering,* Lawrence Erlbaum, Philadelphia, PA

[11] Woods, D.D., Roth, E.M. (1988). *Cognitive Systems Engineering.* In M. Helander (Ed.), Handbook of Human-Computer Interaction. New York, North-Holland

[12] Vicente, K. (2003). *The Human Factor: Revolutionizing the Way People Live with Technology*, A. Knopf, Canada

[13] Nardi. B.A. (2002). *Coda and Response to Christine Halverson*, Kluwer Academic Publishers, Palo Alto, CA

[14] Rogers, Y. (2000). Recent theoretical developments in HCI: their value for informing system design

[15] Hutchins, E. (1994). *Cognition in the Wild.* MIT Press, Cambridge, MA.

[16] Hollan, J., Hutchins, E., & Kirsh, D. (2000). Distributed cognition: Toward a new foundation for human-computer interaction research. ACM Transactions on Computer-Human Interaction**,** 7, 2, 174-196.

[17] Rasmussen, J. (1986). *Information Processing and Human-Machine Interaction: An Approach to Cognitive Engineering,* Elsevier Science Inc., New York, NY

[18] Fidel, R. & Pejtersen, A.M. (2004) From information behaviour research to the design of information systems: the Cognitive Work Analysis framework. *Information Research*, **10**(1) paper 210

[19] Burns, C. M. (2000). Putting it all together: Improving display integration in ecological displays 2000

[20] Burns, C. M., Bryant, D. J. and Chalmers, B. A. (2000) *Boundary, purpose, and values in work domain models: Models of naval command and control*

[21] Vicente, K. J. (1999). *Cognitive Work Analysis: Towards Safe, Productive, and Healthy Computer-Based Work*, Laurenz Erlbaum Ass., New Jersey

[22] Mitchell, C.M. (1996). Models for the design of human interaction with complex dynamic systems. In *Proceedings of CSEPC 96: Cognitive Systems Engineering in Process Control* (pp. 230-237). Kyoto, Japan

[23] Shepherd, A. (1993). An approach to information requirements specification for process control tasks. *Ergonomics*, 36, 1425-1437

[24] Rasmussen, J. (1974). *The human data processor as a system component: Bits and pieces of a model,* Danish Atomic Energy Commission, Roskilde, Denmark

[25] Naikar, N.; Hopcroft, R., & Moylan, A. (2005). *Work Domain Analysis: Theoretical Concepts and Methodology*, DSTO Defence Science and Technology Organisation, Victoria, Australia

[26] Burns, C.M.; Bryant, D.J., & Chalmers, B.A. (2001). Scenario Mapping with Work Domain Analysis, *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*

[27] Vicente, K.J., Christoffersen, K., & Pereklita, A. (1995). Supporting operator problem solving through ecological interface design, *IEEE Transactions on Systems, Man, and Cybernetics,* 25, 529-545

[28] Christoffersen, K., Hunter, C.N., & Vicente, K.J. (1996). A longitudinal study of the effects of ecological interface design on skill acquisition, *Human Factors*, 38, 523-541

[29] Hajdukiewicz, John R.; Burns, Catherine M.; Vicente, Kim J.; Eggleston, Robert G. (1999). *Work Domain Analysis for Intentional Systems*, Human Factors and Ergonomics Society, Palo Alto, CA

[30] Hajdukiewicz., J.R. (1998). *Development of a structured approach for patient monitoring in the operating room.*MASc thesis, Toronto

[31] Salmon, P.M.; Regan, M.; Lenné, M.G.; Stanton, N.A., & Young, K. (2007). *Work Domain Analysis and Intelligent Transport Systems: Implications for Vehicle Design*

[32] Salmon, P.M., Stanton, N, Walker, G., & Green, D. (2004). Future battlefield visualisation: Investigating data representation in a novel C4i system. In V.Puri, D., Filippidi, P., Retter & J.Kelly (Eds) Weapons, Webs and Warfighters. Proceedings of the land Warfare Conference, DSTO, Melbourne

[33] Ahlstrom, U. (2005). Work Domain Analysis for air traffic controller weather displays, *Journal of Safety Research* 36, 159-169

[34] Ferber, J. (1995). *Multi-Agent Sytems*, Addison-Wesley, Muenchen, Germany

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