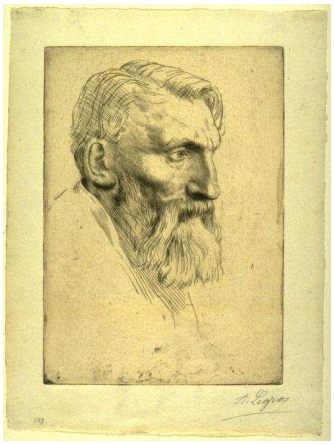
Information Society Technologies

Project IST-511599
RODIN
"Rigorous Open Development Environment for Complex Systems"



RODIN Deliverable D4

Traceable Requirements Document for Case Studies

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Public Document

28 February 2005

http://rodin.cs.ncl.ac.uk/

Contents

SECTION1. INTRODUCTION

This document presents the results of the requirements elicitation and analysis conducted for the case studies in RODIN. Usually these processes lead to creating requirements specification – a document serving as a contract between customers and developers of a system. The term *requirements specification* has a very broad meaning: it might be a document written in plain English, a graphical model, a formal mathematical model, a collection of scenarios or prototypes, or any combination of these. Usually a written document (we call it the *requirements document*) combining natural language descriptions and graphical models is considered to be the most suitable style to describe the requirements for large systems.

The requirements document in such a style has been created by J.-R. Abrial in the process of formal development of controlling software for industrial press [1.1]. The development started from writing the requirements document and the reference document. The requirements document essentially consisted of explanatory text in plain English, diagrams illustrating system functionality and requirements definitions. The requirements were arranged according to a certain taxonomy and indexed. The taxonomy was used to structure the requirements according to various views on system behaviour. The indexes helped in referencing and tracing the requirements in the development process. The reference document contained only the requirements definitions extracted from the requirements document. These documents were found indispensable in the formal development of the system. They were used to eliminate requirement ambiguities, create formal specifications and validate overall system design. The success of this system development has motivated the project members to adopt such a document style while creating the requirements documents for the RODIN case studies. The experience in creating requirements documents and formal system development in the Event-B framework was shared by J-R.Abrial at the tutorial given for participants of RODIN in the beginning of December 2004. As a result, the requirements documents for three case studies are written following Abrial's approach.

The requirements document for case study 1 – *Formal Approaches to Protocol Engineering* – is presented in Section 2 of this deliverable. The document has been created from several sources: informal official requirements on 3GPP Positioning System, a set of UML models describing the positioning service, and documents on the Lyra development method. The requirements document adopts Abrial's style. Our next steps will be to develop formal specification of 3GPP Positioning System by applying formal modelling techniques of the B Method. We are also planning to apply general refinement/decomposition techniques to be developed in WP2, and investigate applicability of formal reasoning techniques for fault tolerance in the area of telecommunications.

Section 3 contains requirements document for case study 2 – *Engine Failure Management System*. The work on this document has explored the use of models in requirements with a view to making a specification generic and providing instances of the generic specification. We have also experimented with the expression and integration of

requirements using UML. The current plan is to continue work in requirement engineering with our academic partner to gain insights into providing a well formed specification. A formal UML-B model will be developed from the requirement work. The work is expected to progress by developing the link with UML_B and the design issues it raises and demands it might impose on the methodology.

The requirements specification for case study 2 is novel in that it presents the functional requirements of the case as generic and traces the requirement to parameterised tables of an application. The specification is also unique in that it expresses the taxonomy of requirements and their relationships in a UML diagram style. This will assist in developing the generic model in line with the UML_B approach adopted for the case study. The modelling and verification of the generic requirement from parameterised tables provides a particular focus to drive development of the ProB tool and UML_B approach and presents specific challenges to scalability of an application and its effects on the tools.

Unlike the previous section, Section 4 contains requirements document for case study 3 – *Formal Techniques within an MDA Context* – written in an unstructured manner as plain English text. As explained in this section such a style is needed to support further experimenting with requirements engineering within this case study. The role of the requirements document for case study 3 is to outline the requirements process, the plan of work and the initial set of informal (or even semi-formal) requirements for the MITA End-to-End architecture. Additional architectures will be made available during the course of the RODIN project as detailed requirements become available. The case study can be split into a number of phases:

- Construction and Formalisation of E2E Model
- Construction and Formalisation of Security Model
- Mapping of Security Model against E2E Model
- Construction of Simple Application utilising both E2E and Security Concepts

For the E2E and Security framework modelling stages we expect a demonstration of the internal consistency of the models produced. When mapping the security model against the E2E model we will have a number of options regarding which parts of the E2E should take the responsibility for the various security related functionality. It is also conceivable that the security model and the E2E do not exactly fit - we then need to explore the ramifications of such a situation with regards to the consistencies of the E2E and security models. Finally the construction of a simple application (to be decided) that utilizes both the security and E2E frameworks will be made. Again this application itself must be internally consistent and be consistent with the architectures/frameworks employed.

Section 5 contains the requirements document for case study 4 – *CDIS Air Traffic Control Display System.* This document is written using the proprietary format as explained in the introduction to this section. Praxis is particularly interested in understanding how well Event B supports the structuring of a large specification of the scale of the CDIS specification. For this reason it is important to cover a large part of the original high level specification in the high-level Event B specification. Taking a vertical

slice down through the system structure preserves the many levels of detail in the original system while keeping the subset size tractable.

The original documents developed by Praxis have been reduced to the subset that forms the basis of this case study. Included here is the requirements document for our subset, presented within the original context that CDIS was built. We feel that it is important not to lose this context as we redevelop the subset of the CDIS system. Updating this document to reflect the context of RODIN CS4 is neither necessary nor desirable for the purpose of developing the case study materials to a position where they may be usefully analysed by the WP3 tool kernel and WP4 plugins. Furthermore, the original context and methods used will make for an excellent comparison against the emerging WP2 methodology.

Fault tolerance issues are covered in the specification document, which is much larger than the requirements document included here. Remaining fault tolerance issues – primarily concerning delays and user error – will be examined during the redevelopment.

Praxis are also interested in understanding how well Event-B refinement supports the formal development from the high-level specification to the detailed design, in particular, the introduction of distribution in the design. This relationship between the high-level specification and the detailed design was not formally established in the original development as the refinement techniques available at the time were deemed inadequate. We believe it will be sufficient to focus on the refinement of a subset of the full Event-B high-level specification to develop useful transferable results on refinement for systems like CDIS.

To this end, approximately one quarter of the material will be redeveloped in Event-B notation in the near term. This will allow the experience of a fully developed project to inform the development of the RODIN methodology and notation. The initial material and remaining portions will be used to evaluate the RODIN tools as they are developed.

Section 6 defines the requirements of the first scenario of case study 5 (Ambient Campus) - the Ambient Lecture scenario. This case study will investigate a number of related scenarios (see deliverable D2 for a more detailed discussion of our possible choices). This particular scenario allows us to apply and demonstrate the project results in development, modelling and verification of fault tolerant mobile asynchronous systems. While creating this scenario, we also performed some initial experimental work with a chosen coordination-based mobility middleware (Lime) and developed a novel exception-handling mechanism for applications developed in this paradigm. Next we will focus on specification of this scenario, on its formal modelling using one of the RODIN formalisms (most likely B), on application of the mobility abstractions which are under development in WP2 and on preparation of the second scenario. We are planning to apply the general refinement/decomposition techniques to be developed in WP2 and to progress further in our programming experiments. Later on we will evaluate the applicability of the process-based modelling techniques (WP2) in this case study and apply the mobility

plug-in (WP4) to model-check mobility-specific properties of the Ambient Campus scenarios.

The requirements documents presented in these deliverable define the systems that will validate RODIN's tools and methodologies. The documents have been created in a close co-operation between academic and industrial partners. This work has facilitated knowledge exchange, tightened co-operation and helped to achieve a common understanding of research goals.

1.2. References

[1.1]. Available via http://se.inf.ethz.ch/teaching/ws2004/0271/index.html#reading

SECTION 2. REQUIREMENTS DOCUMENT FOR CASE STUDY 1: FORMAL APPROACHES IN PROTOCOL ENGINEERING

2.1 Introduction

This case study investigates application of formal methods for development of telecommunications protocols. Telecommunications systems tend to be very large and data intensive. Such systems provide their services by co-ordinating several subservices distributed over the network. The protocol engineering group at Nokia has developed the "Lyra" method which supports the service-oriented approach to protocol engineering. The main goal of this case study is to provide support (in the form of formal techniques and tools) for various stages of this approach. The proposed tools and techniques will be validated by the development of a *Position Calculation Application Part (PCAP)* specified by the *Third Generation Partnership Project (3GPP)*. PCAP is part of the *User Equipment (UE)* positioning system in the UMTS radio access network. PCAP is specified to manage the communication between the network elements *Radio Network Controller (RNC)* and *Stand-alone Assisted Global Positioning System Serving Mobile Location Centre (*SAS). The requirements document for PCAP is presented in this deliverable.

Usually telecommunications systems are verified by using model checking techniques. However, model checking is prone to the state explosion problem, when applied to large systems. One of the goals of this case study is to investigate the use of refinement techniques to prove decomposition and distribution steps. Hence the important problem to be tackled within the case study is a combination of refinement and model checking verification techniques. Another topic to be investigated within case study is the applicability of techniques for formal reasoning about fault tolerance in telecommunications.

The key research tasks in this case study are:

- development of formal techniques and tools to support automation of rigorous design flow (described by the "Lyra" method),
- combination of refinement and algorithmic verification techniques in the development of distributed communicating systems and communication protocols,
- development of formal techniques and tools to support automation of data abstractions,
- application of formal reasoning techniques for fault tolerance in the distributed communication systems and communication protocols domain.

2.2 Requirement Taxonomy

Below we present the Requirements Document for The Third Generation Partnership Project (3GPP) positioning service. The system requirements are given in boxes. An explanatory text surrounding the boxes should assist in understanding the requirements.

The requirements are given names. They are given in boxes in **bold** font. The naming of requirements is organised using the following taxonomy:

- **ARC** – architecture: describes architecture of the system and what each part includes,
- **FUN** – functionality: describes functional behaviour of components and constraints,
- **COM** – communication: describes how distributed components communicate with each other.

2.3 System Architecture

The Third Generation Partnership Project (3GPP) provides a positioning service for calculating the physical location of user equipment (UE) in a Universal Mobile Telecommunication System (UMTS) network. Positioning is based on determining the geographical position of the UE by measuring radio signals. Communication between all network elements is done by using predefined signalling protocols.

UMTS Network Architecture related to position calculation is shown on Fig.1. The abbreviations used in the figure stand for:

- RNC – Radio Network Controller,
- SAS -- Stand-Alone Assisted Global Positioning System Serving Mobile Location Centre,
- UE – User Equipment,
- LMU – Location Measurement Unit.

RNC and SAS are the network elements responsible for providing the positioning service. To calculate a position estimate, they need additional measurement data from UE and LMU devices, which are contacted via intermediate base stations.

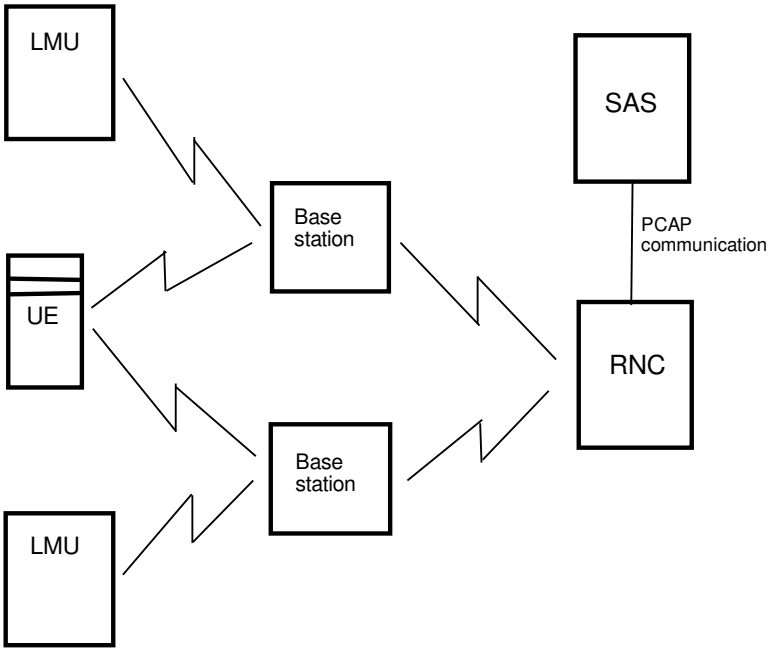

Fig.2.1 Architecture of the positioning system

ARC1.
The positioning system in the UMTS network consists of the following distant network elements: Radio Network Controller (RNC), Stand-Alone Assisted Global Positioning System Serving Mobile Location Centre (SAS), several of Location Measurement Units (LMU) and User Equipment (UE) devices.

UE is a mobile device that is recognised and supported by the UMTS network.

ARC2.
Every UE has a unique ID.

Authentication of UE is outside of the scope of the case study. Hence we assume that every UE has a valid ID.

ARC3.
Every UE has a valid ID.

UE (i.e., a client associated with UE) can send a positioning request to the UMTS network. The network element that is the recipient of a positioning request is Radio Network Controller (RNC).

FUN1.
Positioning requests are sent by UE and received by RNC.

The UMTS network should always respond to the positioning request either by sending a positioning estimate or error message.

FUN2.
RNC replies to every positioning request either by sending the positioning estimate or error message.

We assume that there is only one positioning request at any instance of time. In practice, if there are several simultaneous requests, RNC creates slave processes (threads) for each of them. In this case study, we do not consider concurrency and assume that there is only one process in the system.

FUN3.
There is only one positioning request at any instance of time.

In general a positioning request can have a number of various parameters. For instance, in case the UE is an "advanced device" it can also estimate its own position and forward this information in the request. In this case, the device can receive a position estimate with even higher accuracy. However, this feature is optional and is not considered in the case study. Nevertheless, each request contains the expected accuracy as a parameter of the request. The estimate should fulfil this accuracy otherwise the request is considered as failed.

FUN4.
Positioning request consists of UE ID and position accuracy. The accuracy is represented as a numerical value.

The calculated positioning estimate is returned in the form of geographical or cell-based coordinates together with the positioning accuracy that was achieved. Modelling realistic representation of the coordinates is outside of the scope of the case study. We assume that a position estimate is defined by a couple of numerical values.

FUN5.
Reply to the positioning request contains a couple of numerical values representing co-ordinates and a single numerical value representing the achieved accuracy.

The received position estimate is considered successful if it is done with the accuracy that is requested or higher. If the desired accuracy was not achieved, the request is considered to be failed.

FUN6.
If the position estimate meets required accuracy defined in **FUN5** then the estimate is successful. Otherwise it is failed.

The UE can cancel the (previously sent) positioning request by sending the "positioning abort" request to RNC. In response, RNC terminates execution of the positioning request and returns the "abort confirmation" message to the UE.

FUN7.
UE can send the "positioning abort" request to RNC. The request contains UE ID.

FUN8.
RNC responds to the "positioning abort" request by terminating position calculation and returning the "abort confirmation" message to UE.

Radio Network Controller (RNC) is a UMTS network component, which contains functionality required to support UE position calculation. It controls the flow of positioning requests. RNC is responsible for positioning method selection and position calculation, and provides overall positioning coordination and control.

RNC coordinates UMTS resources (including base stations, Location Measurement Unit (LMU) devices, the SAS, position calculation functions – see below) to calculate an UE position estimate and returns the result to UE.

ARC4.
RNC is a UMTS network component providing overall coordination and control for UE position calculation.

RNC has Radio Network Database (RND), which contains information about approximate network positions of UE devices as well as precise physical coordinates of base stations. This information can be used for UE position calculation.

ARC5.
RNC contains Radio Network Database (RND). RND contains approximate positions of UE devices and the physical coordinates of base stations.

RNC can send a request to RND asking for approximate position of a particular UE. RND responds by sending a list of base stations in which area the UE is currently operating.

If RND is unable to provide the requested data, it responds with the corresponding error message. In that case, RNC can repeatedly send additional measurement requests to RND. The number of additional requests depends on the current working load in the network and the user type but it cannot exceed the predefined number of attempts N_{RND}.

FUN9.
RNC can send RND a “UE position” request, which includes UE ID as a parameter.

FUN10.
RND responds to RNC “UE position” request by providing a list of base stations currently surrounding UE .

FUN11.
If RND is unable to provide the requested data, it responds with the corresponding error message. In that case, RNC can repeatedly (up to the predefined number of attempts N_{RND}) send additional measurement requests to RND.

RNC can send a request to UE asking it to perform radio signal measurements needed for UE position estimate calculation. RNC uses the approximate UE position (i.e., a list of base stations surrounding UE) obtained from RND to contact UE.

One of the position calculation methods currently used is OTDOA – the Observed Time Difference of Arrival method. OTDOA uses measurements of the time difference between arrived radio signals from different base stations surrounding UE. The measurements from at least two pairs of base stations are needed for calculation. To obtain the time measurements, RNC contacts UE via at least three different base stations. UE makes necessary time measurements and sends them back to RNC.

FUN12.
RNC can send UE a request to make local radio signal measurements. The request includes approximate UE position (obtained from RND) as a parameter.

FUN13.
We assume that UE has capability to make requested radio measurements and send radio measurements back to RNC. The response includes requested radio measurements (as numerical values).

FUN14.
If UE is unable to make required calculations, it responds with the corresponding error message. In that case, RNC can repeatedly (up to the predefined number of attempts N_{UE}) send additional measurement requests to UE.

Stand-Alone Assisted Global Positioning System Serving Mobile Location Centre (SAS) is an UMTS network element containing a database of location calculation functions. SAS is controlled by RNC. RNC forwards the positioning data to SAS, which uses one of available calculation functions to calculate a position estimate and then returns the result to RNC. The choice of a particular calculation function is outside of the scope of this case study.

For example, to apply the OTDOA method, RNC forwards timing measurements of radio signals obtained from the UE and exact physical locations of base stations (obtained from RND) to SAS. SAS then uses the hyperbolic triangulation method to calculate the UE position estimate.

ARC6.
SAS is an UMTS network element containing location calculation functions.

FUN15.
SAS applies a certain function to calculate a position estimate and then return the estimate together with the positioning accuracy to RNC. The input data for this are described in **FUN22**.

FUN16.
RNC requests SAS to calculate a position estimate. The request contains radio signal measurements made by UE (see **FUN13**) and base station location data obtained by RNC from RND (see **FUN10**).

FUN17.
If position calculation is successful (see **FUN23**), SAS responds to RNC by sending a position estimate and the achieved accuracy.

FUN18.
If SAS is unable to make the requested calculations (see see **FUN21** and **FUN24**), it responds with the corresponding error message.

To calculate a UE position estimate, SAS needs additional local reference data, which can be provided by Location Measurement Units (LMUs). LMUs are stacionary devices that are capable to constantly monitor closest base stations and do some specific measurements related to them. For example, for OTDOA method, LMUs measure relative time difference of internal clocks of the surrounding base stations. This information is needed to synchronise time measurements received from UE.

FUN19.
SAS sends local reference data requests to one or several LMU.

FUN20.
If LMU successfully makes required measurements, it responds to SAS by sending the requested local reference data.

FUN21.
If LMU is unable to make required measurements, it responds with the corresponding error message. In that case, SAS can repeatedly (up to the predefined number of attempts N_{LMU}) send additional measurement requests to LMU.

SAS contains a database of position calculation functions that calculate a position estimate on the basis of different data or different calculation method. For simplicity, we assume that there is a function that takes three parameters (UE measurements, LMU measurements, and RND data about physical locations of base stations) and returns a pair – the UE position estimate (a pair of numerical values) and achieved positioning accuracy.

FUN22.
SAS invokes a position calculation function with the input parameters: UE measurements, LMU measurements and the physical locations of base stations.

FUN23.
If position calculation is successful, the invoked position calculation function returns the position estimate together with the positioning accuracy (see **FUN5**).

FUN24.
If the positioning accuracy achieved by the calculation function does not meet the accuracy requirement (see **FUN4**), the corresponding error message is returned. In that case, SAS can repeatedly (up to the predefined number of attempts N_{Algo}) invoke the position calculation function.

The functional requirements describing system communication between different network components are summarised in Table 2.1.

Table 2.1 Functional requirements for communicating components

Requesting component	Responding component	Functional requirements
UE	RNC	FUN1, FUN2, FUN7, FUN8
RNC	RND	FUN9, FUN10, FUN11
RNC	UE	FUN12, FUN13, FUN14
RNC	SAS	FUN16, FUN17, FUN18
SAS	LMU	FUN19, FUN20, FUN21
SAS	Position Calculation	FUN22, FUN23, FUN24

2.4 Services and interfaces

In this chapter we will describe the system behaviour in terms of its services and interfaces. From this point of view, the system consists of several layers representing it at different levels of detail. The top layer describes system's interaction with an external user: what services the system provides, what signals it sends and receives. Each consequent layer describes more system implementation details, so that the bottom layer defines the information transfer between actual network elements.

2.4.1 Layer 1

On the top layer, there is software component Positioning which supports the following interface with the external user (usually called upward interface): it accepts two incoming signals (POSITIONING_REQUEST and POSITIONING_ABORT) and responds with two possible outgoing signals: POSITIONING_CONFIRM and POSITIONING_FAIL_CONFIRM). Each of these signals has certain information attached in the form of signal parameters.

COM1.
The user can send POSITIONING_REQUEST signal to Positioning requesting positioning service (see **FUN1**, **FUN4**). The signal parameters are UE ID and positioning accuracy.

COM2.
The user can send POSITIONING_ABORT signal to Positioning requesting to cancel previously requested positioning service (see **FUN7**). The only parameter of this signal is UE ID.

COM3.
Positioning can respond to the user with POSITIONING_CONFIRM signal, if the positioning request was successfully completed (see **FUN2**, **FUN5**). The signal parameters are the position estimate and achieved positioning accuracy.

COM4.
Positioning can respond to the user with POSITIONING_FAIL_CONFIRM signal, if the positioning request failed or was cancelled by the user (see **COM2, FUN2, FUN8**). The signal parameter is error message describing the cause of a failure.

2.4.2 Layer 2

The second layer describes how the positioning service is decomposed into several subservices of smaller grannularity. Each of subservices is provided by an external service component responsible for its execution. The downward interface of the Positioning component has to be extended to define signals to and from the subservice components it relies on.

The positioning service consists of four subservices: DB Enquiry, UE Enquiry, LMU Measurement, and Algorithm Invocation. These services should be executed in the order presented.

The software component Positioning is also decomposed into ServiceDirector, which is responsible for orchestrating the execution of the whole service, and four "handlers" – subcomponents responsible for communication with the corresponding external service components. There are correspondingly four handlers: DBHandler, UEHandler, LMUHandler, and AlgoHandler.

Since ServiceDirector replaces the service component Positioning, it implements the upward interface provided by Positioning.

COM5.
ServiceDirector can accept POSITIONING_REQUEST and POSITIONING_ABORT signals sent by the user, and can respond with POSITIONING_CONFIRM and POSITIONING_FAIL_CONFIRM signals (see **COM1, COM2, COM3, COM4**).

In addition, ServiceDirector can send an initiating service request signals to the corresponding handlers, attaching necessary data as signal parameters. The handlers forward this request, by sending a signal to the corresponding external service components. Once the external component finishes its request, it returns a signal informing about success (with some data describing the result of service execution) or a failure (with some error message attached) of a subservice to the handler. The handler then relays this signal to the ServiceDirector.

In addition to being simple mediators between ServiceDirector and the corresponding service components, the handlers also contain simple fault tolerance mechanisms. In particular, a handler analyses the error message and other data received from a service component, and decides whether sending an additional service request is needed. In other words, if a handler decides that erroneous situation is recoverable, it can repeatedly try to send service requests. Otherwise (i.e., error is unrecoverable), a handler reports the error to ServiceDirector by sending the corresponding error message.

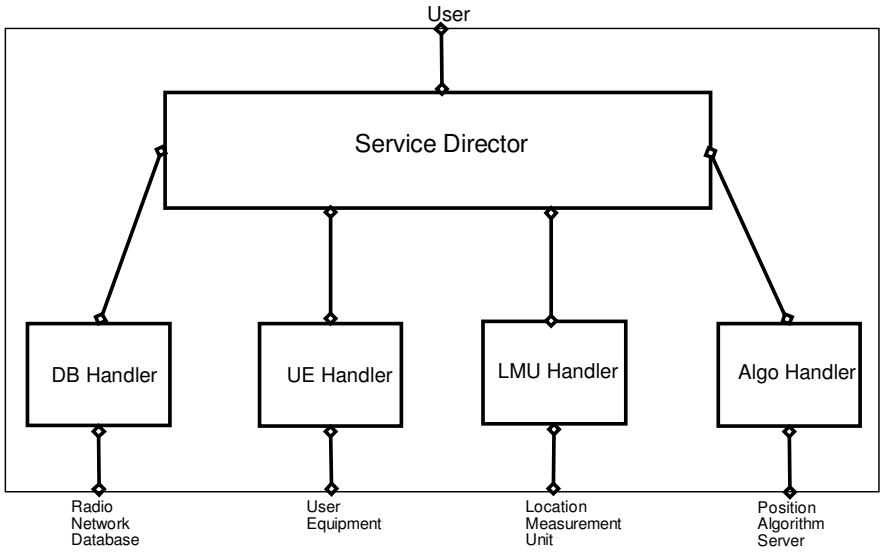

Fig.2.2 Functional architecture of Layer 2

Let us now to formulate requirements for four handlers of the positioning service. For DB Enquiry, we have the following requirements.

COM6.
ServiceDirector can initiate DB Enquiry by sending DB_HANDLER_REQUEST signal to DBHandler. The UE ID is a parameter of the signal.

COM7.
After receiving DB_HANDLER_REQUEST signal from ServiceDirector, DBHandler sends DB_REQUEST signal to Radio Network Database(RND). The UE ID is a parameter of the signal (see **FUN9**).

COM8.
If RND enquiry was succesfully completed, RND responds by sending DB_RESPONSE signal to DBHandler. DB data describing a list of base stations surrounding UE are included as signal parameters. See also **FUN10**.

COM9.
If RND enquiry failed, RND responds by sending DB_FAILURE signal to DBHandler. Error message describing the cause of a failure is included as a signal parameter. See also **FUN11**.

COM10.
After receiving DB_FAILURE signal from RND, DBHandler can repeatedly send DB_REQUEST signal to RND, asking to execute the database enquiry again (see **FUN11**).

COM11.
If DBHandler decides that DB Enquiry was succesfully completed, it sends DB_ENQUIRY_RESPONSE signal to ServiceDirector. The list of base stations (obtained from RND) is included as a parameter.

COM12.
If DBHandler decides that DB Enquiry has unrecoverably failed, it sends DB_ENQUIRY_FAILURE signal to ServiceDirector. The error message describing the cause of a failure is included as a parameter.

For UE Enquiry, we have the following requirements.

COM13.
ServiceDirector can initiate UE Enquiry by sending UE_HANDLER_REQUEST signal to UEHandler. The UE ID and UE position data received from RND are included as parameters of the signal.

COM14.
After receiving UE_HANDLER_REQUEST signal from ServiceDirector, UEHandler sends UE_MEASUREMENT_REQUEST signal to the UE. The UE ID and UE position data received from RND are included as parameters of the signal. See also **FUN12**.

COM15.
If UE enquiry was succesfully completed, the UE responds by sending UE_MEASUREMENT_RESPONSE signal to UEHandler. Radio measurements data calculated by the UE are included as signal parameters. See also **FUN13**.

COM16.
If UE enquiry has failed, the UE responds by sending UE_MEASUREMENT_FAILURE signal to UEHandler. Error message describing the cause of a failure is included as a signal parameter. See also **FUN14**.

COM17.
After receiving UE_MEASUREMENT_FAILURE signal from the UE, UEHandler can repeatedly send UE_MEASUREMENT_REQUEST signal to the UE, asking to execute the UE enquiry again. See also **FUN14**.

COM18.
If UEHandler decides that UE Enquiry was succesfully completed, it sends UE_ENQUIRY_RESPONSE signal to ServiceDirector. The radio measurements calculated by the UE are included as parameters.

COM19.
If UEHandler decides that UE Enquiry has unrecoverably failed, it sends UE_ENQUIRY_FAILURE signal to ServiceDirector. The error message describing the cause of a failure is included as a parameter.

For LMU Measurement, we have the following requirements.

COM20.
ServiceDirector can initiate LMU Measurement by sending LMU_HANDLER_REQUEST signal to LMUHandler. The UE ID and UE position data received from RND are included as parameters of the signal.

COM21.
After receiving LMU_HANDLER_REQUEST signal from ServiceDirector, LMUHandler sends LMU_MEASUREMENT_REQUEST signal to LMU. The UE ID and UE position data received from RND are included as parameters of the signal. See also **FUN19**.

COM22.
If LMU enquiry was succesfully completed, the LMU responds by sending LMU_MEASUREMENT_RESPONSE signal to UEHandler. Radio measurements data calculated by the LMU are included as signal parameters. See also **FUN20**.

COM23.
If LMU enquiry failed, the LMU responds by sending LMU_MEASUREMENT_FAILURE signal to LMUHandler. Error message describing the cause of a failure is included as a signal parameter. See also **FUN21**.

COM24.
After receiving LMU_MEASUREMENT_FAILURE signal from the LMU, LMUHandler can repeatedly send LMU_MEASUREMENT_REQUEST signal to the LMU, asking to execute the LMU measurement again. See also **FUN21**.

COM25.
If LMUHandler decides that LMU Measurement was succesfully completed, it sends LMU_REQUEST_RESPONSE signal to ServiceDirector. The radio measurements calculated by the LMU are included as parameters.

COM26.
If LMUHandler decides that LMU Measurement has unrecoverably failed, it sends LMU_REQUEST_FAILURE signal to ServiceDirector. The error message describing the cause of a failure is included as a parameter.

For Algorithm Invocation, we have the following requirements.

COM27.
ServiceDirector can initiate Algorithm Invocation by sending ALGO_HANDLER_REQUEST signal to AlgoHandler. TheUE position data received from RND, UE measurement data, and LMU measurement data are included as parameters of the signal.

COM28.
After receiving ALGO_HANDLER_REQUEST signal from ServiceDirector, AlgoHandler sends ALGO_INVOCATION_REQUEST signal to the Positioning Algorithm Database. TheUE position data received from RND, UE measurement data, and LMU measurement data are included as parameters of the signal. See also **FUN22**.

COM29.
If Algorithm invocation was succesfully completed, the Positioning Algorithm Database responds by sending ALGO_INVOCATION_RESPONSE signal to AlgoHandler. The calculated UE position estimate and the achieved accuracy are included as signal parameters. See also **FUN23**.

COM30.
If Algorith Invocation failed, the Positioning Algorithm Database responds by sending ALGO_INVOCATION_FAILURE signal to AlgoHandler. Error message describing the cause of a failure is included as a signal parameter. See also **FUN24**.

COM31.
After receiving ALGO_INVOCATION_FAILURE signal from the Positioning Algorithm Database, AlgoHandler can repeatedly send ALGO_INVOCATION_REQUEST signal to the the Positioning Algorithm Database, asking to execute the position calculation again. See also **FUN24**.

COM32.
If AlgoHandler decides that Algorithm Invocation was succesfully completed, it sends ALGO_REQUEST_RESPONSE signal to ServiceDirector. The calculated UE position estimate and the achieved accuracy are included as signal parameters.

COM33.
If AlgoHandler decides that Algorithm Invocation has unrecoverably failed, it sends ALGO_REQUEST_FAILURE signal to ServiceDirector. The error message describing the cause of a failure is included as a parameter.

If any of subservices fail (i.e., ServiceDirector gets the corresponding error signal from one of the handlers), the whole positioning service is considered as failed. ServiceDirector then sends the corresponding error message to the user.

COM34.
If ServiceDirector gets a signal about a failure of any of subservices (i.e., DB_ENQUIRY_FAILURE, UE_ENQUIRY_FAILURE, LMU_MEASUREMENT_FAILURE, ALGO_REQUEST_FAILURE), it sends POSITIONING_FAIL_CONFIRM signal to the user (see **COM4**).

2.4.3 Layer 3

The third layer describes how service components are distributed over the network. ServiceDirector and four handlers are distributed between RNC and SAS network elements. ServiceDirector is further decomposed into two parts – RNC_ServiceDirector and SAS_ServiceDirector.

RNC_ServiceDirector implements the top-level interface with the user. In addition, it supports interfaces for communication with RNC (during DB Enquiry) and UE (during UE Enquiry). In other words, it also implements ServiceDirector – DBHandler and ServiceDirector – UEHandler interfaces.

COM35.
RNC_ServiceDirector can accept POSITIONING_REQUEST and POSITIONING_ABORT signals sent by the user, and can respond with POSITIONING_CONFIRM and POSITIONING_FAIL_CONFIRM signals (see **COM1, COM2, COM3, COM4**).

COM36.
RNC_ServiceDirector can send signals to and accept signals from DBHandler and UEHandler according to the interfaces described in **COM6-COM12** and **COM13-COM19**.

SAS_ServiceDirector supports interfaces for communication with LMU (during LMU Measurement) and Positioning Algorithm Server (during Algorithm Invocation). In other words, it also implements ServiceDirector – LMUHandler and ServiceDirector – AlgoHandler interfaces.

COM37.
SAS_ServiceDirector can send signals to and accept signals from LMUHandler and AlgoHandler according to the interfaces described in **COM20-COM26** and **COM27-COM33**.

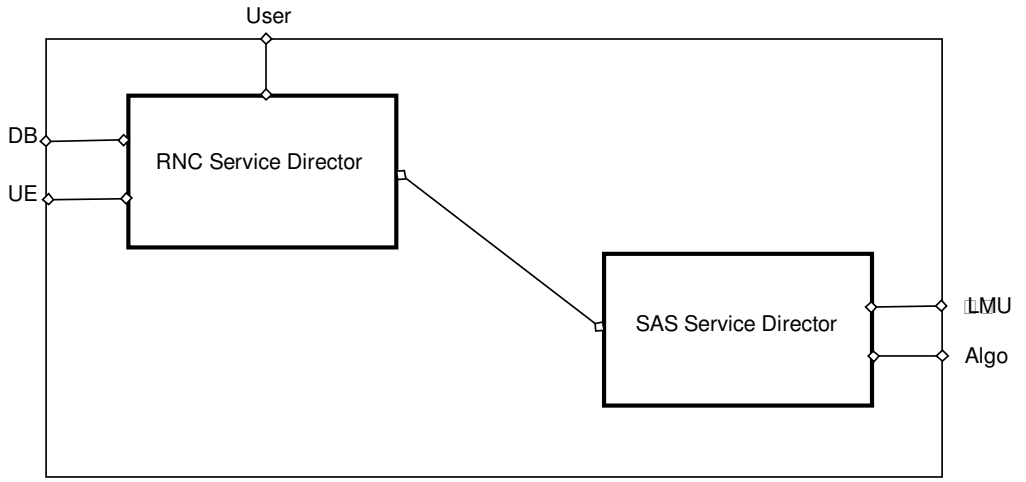

Fig.2.3 Functional architecture of Layer 3

Since ServiceDirector is now split between two distant network elements, we should describe communication between RNC_ServiceDirector and SAS_ServiceDirector, while executing the UE positioning service. The communication is governed by the PCAP communication protocol ([2.1,2.2]). Position Calculation Application Part (PCAP) is a communication protocol and part of the UE positioning system in a UMTS network. PCAP defines the interface and corresponding signalling procedures

to enable the interaction between RNC and SAS network elements in the process of performing a position estimate of the UE.

After completing successfully two first subservices (DB Enquiry and UE Enquiry), RNC_ServiceDirector sends request signal to SAS_ServiceDirector together with data required for finishing position calculation. In response, SAS_ServiceDirector sends signal with the position estimate and achieved accuracy (in case of success) or error message (in case of a failure). Communication is realised using signalling protocols allowing data transfer between distant network elements.

Both RNC_ServiceDirector and SAS_ServiceDirector have subcomponents called Peer Proxies, which are responsible for providing PDU (Protocol Data Unit) communication over the network (according to the PCAP protocol). Peer Proxy encodes outgoing PDU message before sending it to the underlying transport layer. Similarly, Peer Proxy decodes incoming transport service messages containing encoded PDU values. We assume that there are corresponding functions (signals) of the transport layer that realise the actual data transfer.

COM38.
RNC_ServiceDirector can send SAS_REQUEST signal to RNC_PeerProxy. UE ID, UE position data from RND, and UE measurement data are included as parameters. See also **FUN16**.

COM39.
RNC_PeerProxy encodes received data and forwards them to the underlying transport layer, which makes the actual data transfer between RNC and SAS.

COM40.
SAS_PeerProxy decodes received data from the underlying transport layer, and sends SAS_REQUEST signal to SAS_ServiceDirector, attaching the decoded data as parameters.

COM41.
If UE positioning request is successfully completed, SAS_ServiceDirector sends SAS_RESPONSE signal to SAS_PeerProxy. The UE position estimate and the achieved accuracy are included as parameters. See also **FUN17**.

COM42.
If UE positioning request has failed, SAS_ServiceDirector sends SAS_FAILURE_RESPONSE signal to SAS_PeerProxy. The error message indicating the cause of a failure is included as a parameter. See also **FUN18**.

COM43.
SAS_PeerProxy encodes data received from SAS_ServiceDirector and forwards them to the underlying transport layer, which makes the actual data transfer between SAS and RNC.

COM44.
RNC_PeerProxy decodes data received from the underlying transport layer, and, if they indicate successful UE position calculation, sends SAS_REQUEST signal to SAS_ServiceDirector, attaching the decoded data as parameters.

COM45.
RNC_PeerProxy decodes received data from the underlying transport layer, and, if they indicate a failure of UE position calculation, sends SAS_FAILURE_REQUEST signal to SAS_ServiceDirector, attaching the decoded data as parameters.

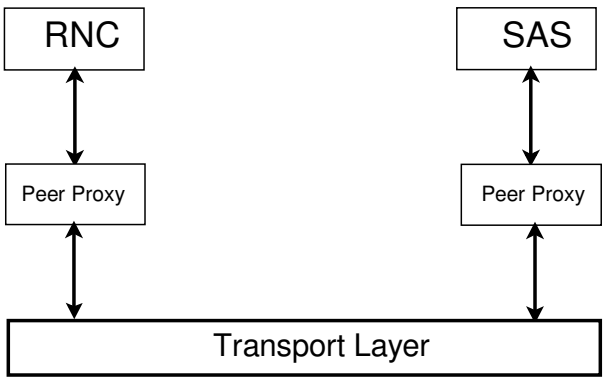

Fig.2.4 Communication between RNC and SAS

2.4.4 References

2.1. 3GPP. Technical specification 25.305: Stage 2 functional specification of UE positioning in UTRAN. See http://www.3gpp.org/ftp/Specs/html-info/25305.htm

2.2. 3GPP. Technical specification 25.453: UTRAN Iupc interface positioning calculation application part (pcap) signalling. See http://www.3gpp.org/ftp/Specs/html-info/25453.htm

SECTION 3. REQUIREMENT DOCUMENT FOR CASE STUDY 2: ENGINE FAILURE MANAGEMENT SYSTEM[1]

3.1. Introduction

An embedded Engine control system comprises of several subsystems. The control subsystem, executes algorithms on its inputs in order to provide the desired fuel demand to the engine.
The engine failure management subsystem provides a protective wrapper to the control subsystem, protecting it from failures in its system inputs and so enhancing the dependability of the control system. It detects failures, and then manages these failures in order to provide the control subsystem with an acceptable input or graceful degradation of behaviour.
This requirement specification describes the functional requirement of the failure management subsystem.

Features of the Engine Failure Management subsystem

Detection of system sensor input failures
Confirmation of system sensor input failures
Temporary actions during confirmation
Failure actions after confirmation
Failure classification
Failure labelling and notification
Degraded action depending upon severity

The specification first describes the generic features of the requirement then later provides an example of a particular instance of such a system in tabular form. The instance is traceable to the generic description by references.

This document is organised into two separate texts (1) The reference text which contains the requirement and assumptions (2) The explanation text, which may give further explanation to the requirement/assumptions and there purpose. The reference text is separated from the explanation text (boxed and given an identifier).

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3.2. Overview of Sub-System Functionality

The subsystem monitors sensor inputs to be used in other (client) subsystems. The subsystem checks the condition of a set of inputs from some external equipment to detect abnormal conditions including transducer failures and failures of the equipment. To avoid reacting to transient noise on the inputs abnormal conditions must be confirmed over a number of readings before any permanent action is taken. During this confirmation period the subsystem must provide acceptable actions in place of using suspect readings. If the abnormal condition is confirmed, more permanent action may be taken to provide longer term acceptable operation of the client subsystems. The following requirements have been given identifiers according to a taxonomy that is described in the next section.

PROC1 The subsystem executes on a given process cycle.

DET1 The subsystem detects abnormal conditions of inputs caused by failures of the external equipment.

OUT1 Inputs that are found to be in a normal condition may be passed on as outputs (if they are required by other subsystems).

CONF1 When an abnormal condition is detected, the subsystem confirms the suspected failure over a period of time. During this time the condition may recover.

ACT1 The subsystem takes some temporary action to simulate acceptable input while a suspected fault is being confirmed.

ACT2 The subsystem simulates acceptable input conditions or performs other permanent failure actions if it confirms an abnormal condition of the inputs.

PROC2
All tests will be implemented by configuring the generic requirements specified in this document to meet the specific requirements of the application (as shown in Tables 3.9.1 to 11).

3.3. Taxonomy

This specification identifies and categorises environmental assumptions (ENV), processing decisions (PROC), functional requirements (FUNC) and performance requirements (PERF) about the failure management subsystem.

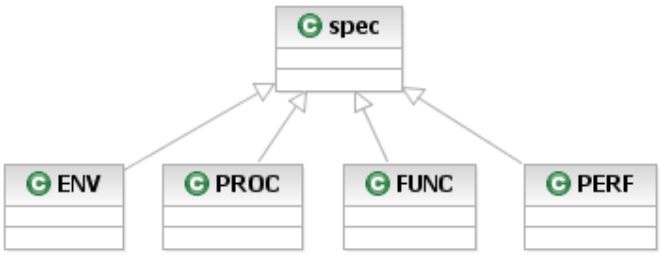

Figure 3.3.1 - Top level classification of specification items illustrated in UML

An input (INP) may have many associated tests and a test may utilise many inputs. A test is made up of a detection method (DET) and confirmation mechanism (CONF) pair. Each test also has a collection of conditions (COND) that must be satisfied for the test to be valid. A confirmation mechanism contains three different actions (ACT), a healthy action, a temporary action (taken while a test is confirming) and a permanent action (taken when a test has confirmed). Each action is associated with at least one output (OUT) that it modifies.

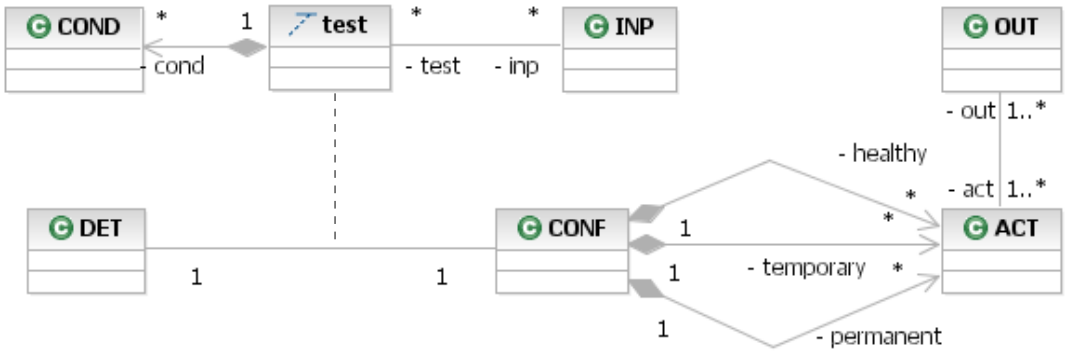

Figure 3.3.2 – Overview of functionality expressed as a UML class diagram

The detection mechanism of a test can be further classified as a comparison of magnitude (MAG), a comparison of rate of change (RATE), a comparison with a predicted value (PRED) or a comparison between several inputs (MULT).
Hence, functional requirements are identified in the following hierarchy.

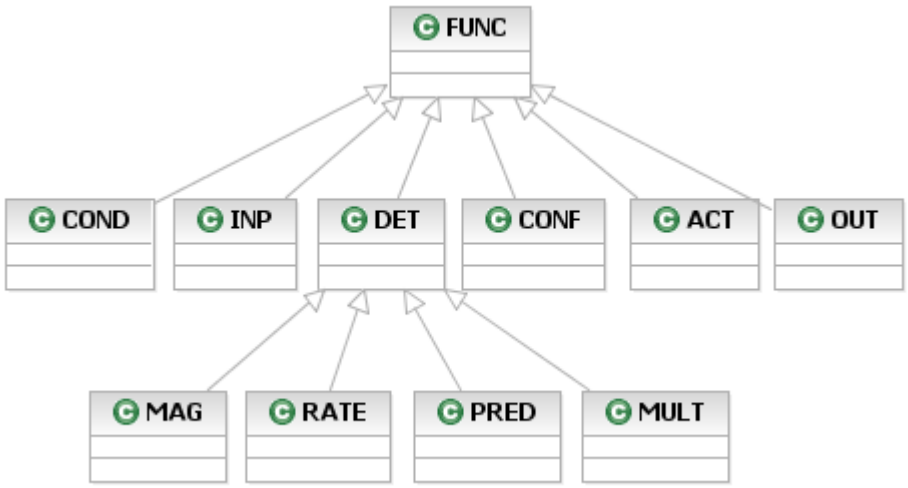

Figure 3.3.3 – Expansion of functional classification

In accordance with this classification, the reference text in this document is organised around, and identified by, the following taxonomy.

Assumptions

ENV - is used to label assumptions about the environment of the failure management subsystem

Decisions

PROC - is used to label decisions about how the system will be processed

Functional requirements

FUNC - is used to label requirements dealing with general functionality not covered by another category.

INP - is used to label requirements about use of inputs

COND - is used to label requirements dealing with conditions under which a test is performed.

DET - is used to label requirements dealing with detection.

DET_MAG - is used when dealing with magnitude test detection.

DET_MULT - is used when dealing with multiple input test detection.

DET_PRED - is used when dealing with predicted value test detection.

DET_RATE - is used when dealing with rate test detection.

CONF - is used to label requirements dealing with the confirmation of failures.

ACT - is used to label requirements dealing with actions taken either normally or in response to failures.

OUT - is used to label requirements about providing outputs

Non-functional requirements

PERF - is used to label requirements dealing with performance.

3.4. Environment

The environment consists of various hardware and software components which provide sensor readings and variables for the failure management subsystem. The failure management subsystem resides within an engine control unit. Other subsystems within the same unit interact with the failure management subsystem.

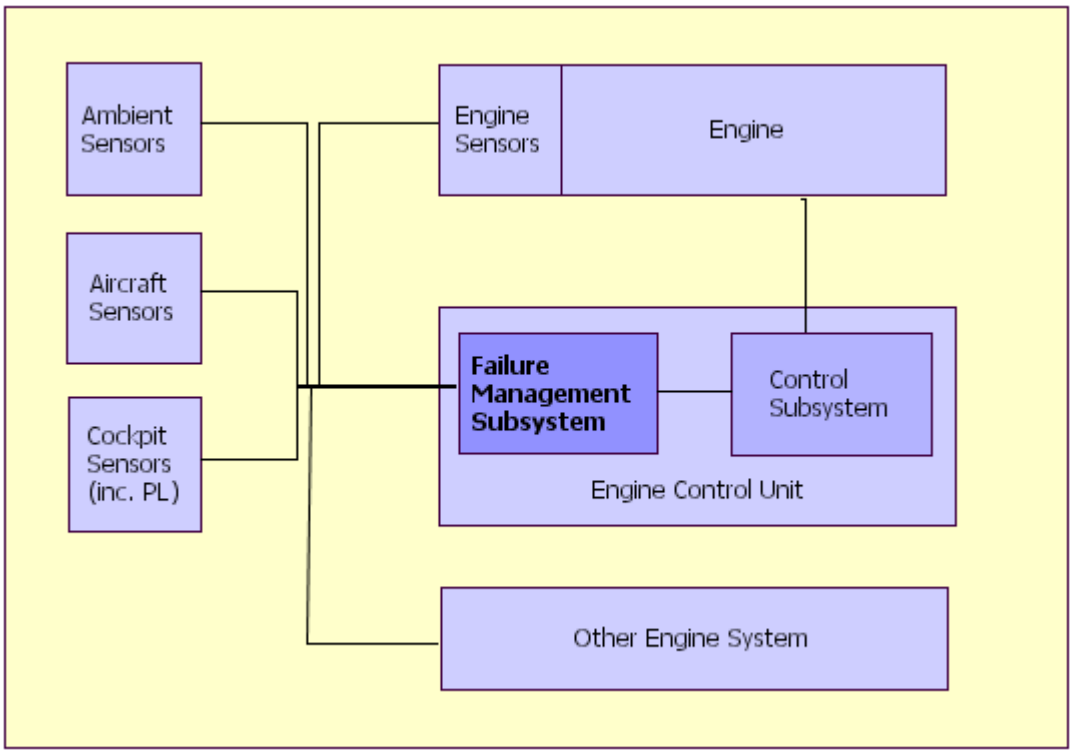

Figure 3.4 – Environment of Failure Management Subsystem

The following components can be identified in the environment of the failure management subsystem within the engine control unit.

ENV1 The subsystem environment consists of Control Subsystem, Engine Control Unit platform including I/O facilities and scheduler.

ENV2 The control subsystem uses the outputs from the failure management subsystem to determine how it should control the fuel flow to the engine.

The following equipment can be identified in the environment of the engine control unit (in which the failure management subsystem operates).

ENV3 The engine control unit environment is the Engine, Ambient Sensors, Aircraft Sensors, Engine Sensors and Cockpit Sensors (including Power Lever PL) and another complete engine system.

Engine

ENV4
The engine can be in the following modes

Start, Start Abort, Lightoff, Running, Shutdown

Engine controller

ENV5
The engine controller performs control of the engine fuel demand based on the controllers inputs

Sensors

A sensor outputs a measurement of the device it is reading. Depending upon the type of sensor it will give either a binary or analogue output. A sensor does not output an error status. In more complicated devices several sensors may be required to be used in combination to provide the reading of a device.

In order to maintain system dependability, a device may have several sensors which are used to measure the same input.

ENV6
One type of sensor produces a binary output.

ENV7
One type of sensor produces an analogue output.

ENV8
A sensor is assumed to read over the full range of the device

ENV9
Some external devices may have multiple sensors whose output can later be combined to provide a device reading.

ENV10
Some external devices may have multiple sensors which provide alternative measurements of the same source

The PL device is essentially a lever device which is used in the cockpit to demand more fuel to the engine. It is an instance of ENV9 that has two sensors (offset and direction) whose output can be combined to provide the full demand reading. It also contains an instance of ENV10 as it has an interlock output which is an abstract representation of lever position. (ie in a locked position or in between).

ENV11
The Power Lever (PL) consists of the offset(PL), directional gain (PLg) and interlock(PLi) Ref ENV9 and ENV10

Where
Lever position – basic analogue range of lever, it can be locked into three positions stopped, idle and full.
Lever offset –magnitude of offset on the idle position
Direction - determines the direction of the offset from the idle position
Interlock – set when the lever is in Stop Idle or Full. It is used for fault detection

ENV12
The PL components operate in the following modes

Lever Position	**Lever in degrees**	**PL offset**	**Lever directional gain PLg**	**Interlock PLi**
Stop	0	30	Off	On
Stop-Idle	0-30	30- 0	Off	Off
Idle	30	0	On or Off	On
Idle- full	30-60	0-30	On	Off
Full	60	30	On	On

The computed output used for control corresponds to the lever demand in degrees. This is derived as follows.

ENV13
When the Directional gain (PLg) is off

PL in degrees = 30° – PL offset

When the Directional gain (PLg) is on

PL in degrees = 30° + PL offset

3.5. Subsystem Interface

The subsystem handles several types of input and output variables described below. The specific variables used are referenced in Tables 3.9.1 & 2 later.

Input
The subsystem uses input variables, which represent sensor readings or settings from other client subsystems. All variables will be represented by digitalised analogue or boolean states.
Where sensors are duplicated then different variables are assigned, the inputs are said to be homogenous. The functionality is as follows:

INP1 The subsystem uses input variables which contain either digitalised values or Boolean states.

INP2 The subsystem input variables represent either sensor values or other subsystem variables.

INP3 The subsystem sensor variables represent the scaled full range of the sensor .

INP4 Some “other subsystem” input variables represent engine states.

INP5 Some “other subsystem” input variables represent the controller state.

INP6 Some “other subsystem” input variables represent the control subsystem output.

Output
The subsystem output variables (values and boolean states) to be used by other client subsystems.

OUT2 The subsystem produces output variables which contain either values or Boolean states.

Variables representing sensor values after failure management
These variables are output to the control subsystem and represent failure managed sensor input values. They may contain the actual input value of a sensor input variable or as in the case of a failed input, some substitute value. In some cases the output variable may be computed from a combination of the actual input values. Where there

are multiple homogenous sensors for the same input only one value will be used. The selection of which sensor value is used is given in the tables.

OUT3 Some subsystem output variables represent sensor values to be used by the control subsystem

OUT4 Some subsystem output variables are computed from a combination of sensor inputs.

OUT5 Some subsystem output variables are derived from a selection of sensor inputs.

Variables that control logic in other subsystems

These variables initiate further actions in the client subsystems, when a sensor input is failing or failed. Typically this may include fault storage and logic to select actions such as system freezing.

OUT6 Some subsystem output variables control logic in other subsystems.

3.6. Failure Management

The subsystem can perform various kinds of test on an input to detect whether the transducer and input circuitry are operating correctly. Some tests may only be performed under certain conditions that depend on the state of the environment
The tests requirements are described in terms of the conditions for applying the test, the type of detection mechanism, the mechanism for confirming the failure and the actions taken.

3.6.1. Test Conditions

A particular test will only be enabled under certain conditions. The conditions for each test are given in Table 3.9.3. These conditions operate on variables and take one of the following forms.

A test may be enabled under all conditions:

COND1 – Perform test under all conditions (i.e. guard = true).

A test may be enabled when a variable is compared against a fixed constant. Where compared against may be greater than, equal to or less than.

COND2 – Perform test if variable >, = or < val (a fixed constant value).

A test may be enabled when a variable is compared against another variable or a function of a variable.

COND3 – Perform test if a variable >, = or < variable or function of variable.

A test may be enabled when a boolean variable is compared against true or false.

COND4 - Perform test if a variable equals true (or false).

Composite conditions may be constructed using a combination of the above forms linked with conjunction and disjunction and negation.

COND5 - Perform test if composite logical condition is true. Eg (con1 AND con2) OR con3.

Once a test has been confirmed as failed it is not re-tested (until the hardware has been re-powered) effectively latching the failed condition. This prevents possibly confusing changes of behaviour if the failure is intermittent.

PROC3 – A test for an input will not be enabled if the input has already been confirmed as failed.

3.6.2. Types of Test

Different types of test have been devised from experience with component and operational failures that have occurred in this domain. The tests operate on sensor inputs only. An input will be in error if the test detects an abnormality. The actions

that are undertaken on the result of a test will depend on the confirmed status of the input and the state of the system this is discussed later (see section 7). Each test may have configurable parameters to allow the characteristics peculiar to a particular sensor input to be configured e.g. its magnitude range. The test instances are referenced in Tables 3.9.4 to 8.

DET2 The subsystem performs detection of errors (failures) on its INP1 inputs using a selection of magnitude, rate and multiple tests. Ref. DET-MAG, DET_RATE, DET_PRED, DET_MULT.

DET3 An input will be in error if a test detects a discrepancy.

DET4 The status of an input will be determined by the confirmation mechanism after test.

Since devices may have single or multi sensor outputs then tests have been developed to cover both these configurations and are described below.

3.6.3. Single Sensor Input Tests

The Magnitude test (Mag)

This type of test is intended to detect abnormal values through the detection of out of device range sensor readings or readings infeasible with the operational state. The input from the sensor is compared to a reference limit(s) which may be specific to the input. (The limit will usually have an upper and lower limit which denotes the range). If the limit is exceeded, then the input is in error otherwise it is in range. The limit may vary as a function of engine state, in some cases a variable limit may be computed from a function of another signal. The specific configuration of each input limit is given in Table 3.9.5.

DET_MAG1 Compares input value against a magnitude (range) limit. The input is in error if the limit is exceeded.

DET_MAG2 The range limit for an input may be variable or fixed.

The Rate test (Rate)

This test is intended to detect incorrect readings when an input value is changing over time. It detects if an input changes too much over a fixed time by comparing the change in value over a fixed time period with a fixed limit. The input is in error if the limit is exceeded.

DET_RATE1
Compares a change in input value over a fixed time interval against a fixed limit. ie ((In-In_{-1})/delta T)>lmt. Where In_{-1} is the previous reading of Input In. The input is in error if the limit is exceeded.

Predicted value test (Pred v)

This test is intended to detect incorrect readings based on the intended operational state of the system. The system predicts a value or range that a particular input may reach over a fixed time period. It can detect where movement is expected but not achieved. In application it can be regarded as a form of magnitude test where limits are constantly varying. However the difference is that the variable limit values are computed from what the control system has expected the engine system to have reached as a result of a control action rather than what the current operational state is. The predicted values may be derived from the control subsystem.

DET_PRED1
Compare input value against a computed value. The input is in error if the discrepancy lies outside a tolerance of this value.

3.6.4. Multiple Homogenous Input Tests

These tests refer to testing devices that have duplicated sensors. Each of the duplicated sensor input is tested first using the single sensor tests. Only inputs that are not in error are then compared. Only one input is chosen for control.

Dual sensor Difference test (Diff)

A comparison between two sensors of the same source are compared and if their difference lies outside a given tolerance then a sensor is in error.

DET_MULT1
Compares an input value against a different input value from the same INP2 source. A chosen input is in error if the difference exceeds a fixed limit.

PROC4
The comparison of input values from the same source are only enabled if the inputs have passed their DET-MAG,DET-RATE or DET_PRED tests.

PROC5
This requirement has been deleted.

3.6.5. Multiple Heterogeneous Input Tests

These tests refer to testing specific devices that have multi sensor outputs that can only have certain combination of values. Incorrect combinations will be considered as the device in error.

DET_MULT2
Device specific tests are identified for PL.

DET_MULT3
Device specific tests involve comparing multi input values from the device.

DET_MULT4
An error will be detected if an Invalid Input combination occurs.

DET_MULT5
Some multi input values are compared against limits in order to set or clear latch states

3.6.6. Test Scheduling

The subsystem applies the tests in two stages and these can be expressed as conditions.

COND6
Groups of tests can be applied in different stages.

COND7
Test Stages may depend on conditions Ref Cond_1, Cond_2,Cond _3, Cond_4.

The frequency of each test execution can be configured. Each test will be undertaken, providing the test conditions associated with it are satisfied. In a multiple input test the timeliness of acquiring the input values to be compared should be considered in order to avoid false detections due to comparison between values representing different points in time.

PROC6
A multi input test should be applied at an interval where the frequency of individual input readings cannot affect the test.

3.6.7. Test Input Status Confirmation

The subsystem needs to be tolerant to isolated errors, which may be transient, so as to maintain stability in the control system. In order to achieve this, a failure confirmation mechanism is employed to confirm when a firm fault has been established. If an input is in error but not confirmed as a fault, then some action may still occur, but the input will still be used if the confirmation recovers (see section below). However once failed, the failure will normally be latched which means it cannot be reset until initial power up and the input is not recoverable. See section on actions below.

CONF2
A sensor input will have been determined to have failed, only if a failure confirmation mechanism has confirmed it.

CONF3
A confirmed failure may be latched. A latched failure cannot be reset until system reset.

The following mechanism is normally used. This mechanism detects persistent failure on an input for consecutive cycles and allows recovery if a limit has not been reached. Tables 3.9.4 to 7 reference instances of the mechanism.

CONF4(persistence counter failure mechanism)
If a test has detected an error (failure) on an input
Then the inputs fault counter for the test will be incremented by a value x. until it reaches or exceeds z it will then be designated as a confirmed failure and no further counting will take place.

If a test has not detected an error on an input (and the signal does not have a confirmed failure)
Then the fault counter will be decremented by a value y, limiting at zero.

Whenever the fault counter is not zero and has not reached a limit z then the input is classified as failing.

The mechanism may have different configurable parameters for each input. The nominal values for x, y and z are 2 &1 and 8 respectively.

It is useful to have a confirmation mechanism which is not directly associated with failures as it can be used to confirm when a state has been reached. This is particularly useful when setting latches when a value has been reached.

CONF5 (confirming persistence of conditions for tests)
If a detection has been made for a number of consecutive readings an action will be taken. (Since this is not a failure confirmation the confirmation immediately returns to its healthy state when the confirmation has been achieved). The confirmation also returns to the healthy state as soon as a single non-detection is made

3.7. Test Result Actions

The actions that may occur after the execution of a test will depend upon the confirmed status of the test input and the state of other variables.

ACT3
Actions will depend upon the status of the input being a) healthy, b)not healthy and not confirmed c) confirmed.

ACT4
Actions will depend on conditional status of other inputs.

If a test is enabled and does not detect an error then the sensor input values will normally be directly output to the control subsystem but may undergo some computation beforehand (e.g. the PL device will have its output to the control system derived from other inputs). Where sensors are duplicated only one sensor input will be chosen to be output to the control. Instances of healthy action are given in Table 3.9.9.

ACT5
Some sensor input variables that are not in error will be output to the control subsystem.

ACT6
Some sensor input variables that are not in error will be combined for output to the control subsystem.

Multiple sensor input selection

Where more than two sensors are duplicated then the system selects the sensor from the inputs by finding the median of the sensors. The median is found by selecting the middle value of a sorted set of sensor values in ascending order. Where the values are even then the middle plus one sensor is chosen.

ACT7
Some healthy multiple sensor input variables need to be selected according to some mechanism before being sent to the control subsystem. Where multiple inputs are available from the same external source ie multiple homogenous inputs. Then the median of the sensor input is chosen from the healthy sensors.

If a test is enabled but detects an error then a temporary action will occur as long as the input has not been confirmed failed.

ACT8
Temporary actions are defined as actions initiated by the subsystem when an input status is being confirmed.

ACT9
This requirement has been deleted.

ACT10
Where a test has found a sensor input variable in error and the sensor input has not already been confirmed failed by the confirmation mechanism, then the input will not be suitable for selection for output to control.

When an input value is in error and its the fault confirmation counter is non zero and has not reached its limit, then the control subsystem will typically be given the last value of the input that has not failed i.e. the last good value. There may be an additional system action such as a system freeze. System freeze refers to setting an output in the failure management subsystem (ref OUT6.1 Table 3.9.2) which will freeze the fuel flow in the control system. The specific temporary action for each input is given in Table 3.9.10.

ACT11
A Temporary action will substitute a value for the erroneous input.

ACT12
A temporary action may set other outputs.

3.7.1. Confirmed Failure Actions

Confirmed failure actions refer to those actions that apply after an input has been confirmed failed by the confirmation mechanism. All confirmed input failures would be identified and logged in the output fault flags (ref Table 3.9.2). All fault flags are latched.
A confirmed action may perform a latched control action i.e. it cannot return to using the original input unless the system is reset on power up. Confirmed failure actions like the temporary actions may substitute values or variables for the failed input and may also set other outputs. The confirmed failure action will depend upon the state of the subsystem and the severity of fault. The specific confirmed action for each input is given in the confirmed action table. Where the confirmed action is severe it is termed a hard fault action then the subsystem generally initiate to freeze the fuel flow rate to the engine by setting the system freeze output. The hard fault action is always latched.
Where the confirmed action is less severe it is termed a soft fault action when this occurs then the subsystem will normally substitute a value to be used by the control subsystem for it's input and may perform some additional control actions through setting of its output variables to the subsystem. The soft fault action will normally be latched.

ACT13 Confirmation Action refers to actions initiated by the subsystem when a sensor input has been confirmed failed by the confirmation mechanism.

ACT14 Upon confirmation of a fault then the transitory failure actions will be superseded by confirmation actions.

ACT15 A confirmation action will substitute a value for the input and may set other control variables.

ACT16 Most confirmed actions are latched.

ACT17 A latched action cannot be reset until the system has been given a reset.

ACT18 A confirmation action that results in a system freeze will always be a latched action.

ACT19 All confirmed faults are classified into two categories of criticality. Hard Faults = Failures that could cause unacceptable operation. Soft Faults = Failures that provide either no impact on normal operation or limited degradation.

ACT20 All confirmed failures (faults) will be logged in fault flags.

ACT21 All fault flags are latched.

3.8. Performance Constraints

PERF1
The rate test interval must not be shorter than the execution cycle.

PERF2
The engine failure management system must be able to perform its worst case tests for all its input within the execution cycle time and within the other demands on the processor time for the cycle.

PERF3
Each input is required to be tested within a frequency consistent with its output usage.

3.9. Specific Requirements for Fm1 Application

The following tables provide the specific requirements for a failure management application Fm1 from which the above generic requirements have been derived and are referenced. The table data is effectively a parameterisation of the generic requirements.

3.9.1. Inputs

This table defines the inputs and their attributes for a particular application instance. For generic description see Subsystem Interface section.

Table 3.9.1.

Ref	Name	Type [INP1]	Range [INP3]	Res	Description	Freq mS
INP5.1	CYCLE_NO	digital	1..16	1	Execution cycle counter (wraps after 16)	24
INP5.2	POWERUP	Boolean	on/off	-	control system in power up phase	24
INP4.1	START_MODE	Boolean	on/off	-	control system performing start	24
INP4.2	LIGHTOFF	Boolean	on/off	-	control system detected engine lit	24
INP4.3	START_ABORT	Boolean	on/off	-	control system aborted start	24
INP4.4	RUN_MODE	Boolean	on/off	-	control system completed start	24
INP6.5	FFp	digitised	0 to 3000pph	0.1 pph	Fuel Flow Predicted	24
INP2.1	ET1	digitised	-200 to 2000°F	0.1°F	Engine Temperature sensor 1	24
INP2.2	ET2	digitised	-200 to 2000°F	0.1°F	Engine Temperature sensor 2	24
INP2.3	ET3	digitised	-200 to 2000°F	0.1°F	Engine Temperature sensor 3	24
INP2.4	ET4	digitised	-200 to 2000°F	0.1°F	Engine Temperature sensor 4	24
INP2.5	ET5	digitised	-200 to 2000°F	0.1°F	Engine Temperature sensor 5	24
INP2.10	ESa	digitised	0-200%	0.01	Engine Speed (main)	24
INP2.11	ESb	digitised	0-200%	0.01	Engine Speed (backup)	24
INP2.12	EP	digitised	0-100psia	0.1	Engine Pressure	24
INP2.13	AP	digitised	0-25psia	0.1	Ambient Pressure	24
INP2.14	APo	digitised	0-25psia	0.1	other engine's AP	24
INP2.15	EQ	digitised	-20-200%	0.1	Engine Torque	24
INP2.16	EQo	digitised	-20-200%	0.1	other Engine's Torque	24
INP2.17	ESo	digitised	0-200%	0.1	other Engine's Speed	24
INP2.18	FFm	digitised	0 to 3000pph	0.1	Fuel Flow	24
INP2.20	PLm	digitised	0 to 30°	0.1	Power Lever (magnitude)	64
INP2.23	OV	digitised	0 to 50v	1v	Voltage OR	24
INP2.24	BV	digitised	0 to 50v	1v	Battery Voltage	24
INP2.27	PLi	boolean	on/off	-	PL interlock test	24
INP2.28	PLg	boolean	on/off	-	PL gain	24
INP2.29	ETo	digitised	-200 to 2000°F	0.1°F	other Engine's Temperature	24

3.9.2. Outputs

This table defines the outputs and their attributes for a particular application instance. For generic description see Subsystem Interface section. Note the digitalised output range is a derived property as a result of limiting the input range (ref Table 3.9.1) through magnitude tests (ref Table 3.9.5) and actions (ref Tables 3.9.9, 10, 11).

Table 3.9.2.

Ref	Name	Type [OUT2]	Range	Res	Description	Freq mS
OUT6.1	FREEZE	Boolean	on/off	-	disable all control	24
OUT6.34	LOADSHARE	Boolean	on/off	-	disable load sharing	24
OUT6.33	DUMP	Boolean	on/off	-	open fuel dump valve	24
OUT5.1	cET	digitised	-100 to 1900	0.1	Engine Temperature	24
OUT5.2	cES	digitised	0 to 130	0.01	Engine Speed (main)	24
OUT3.1	cEP	digitised	1.5 to 200	0.1	Engine Pressure	24
OUT3.2	cAP	digitised	4 to 20	0.1	Ambient Pressure	24
OUT3.3	cEQ	digitised	-10 to 140	0.1	Engine Torque	24
OUT3.4	cEQo	digitised	-10 to 140	0.1	other Engine's Torque	24
OUT3.5	cESo	digitised	0 to 130	0.1	other Engine's Speed	24
OUT3.6	cFF	digitised	-100 to 200	0.1	Fuel Flow	24
OUT3.7	cPL	digitised	0 to 60	0.1	Power Lever	64
OUT3.8	cETo	digitised	-100 to 1900	0.1	other Engine's Temperature	24
OUT6.2	fET1	boolean	on/off	-	Engine Temperature fault flag	Latched
OUT6.3	fET2	boolean	on/off	-	Engine Temperature fault flag	Latched
OUT6.4	fET3	boolean	on/off	-	Engine Temperature fault flag	Latched
OUT6.5	fET4	boolean	on/off	-	Engine Temperature fault flag	Latched
OUT6.6	fET5	boolean	on/off	-	Engine Temperature fault flag	Latched
OUT6.11	fESa	boolean	on/off	-	Engine Speed (main) fault flag	Latched
OUT6.12	fESb	boolean	on/off	-	Engine Speed (backup) fault flag	Latched
OUT6.13	fEP	boolean	on/off	-	Engine Pressure fault flag	Latched
OUT6.14	fAP	boolean	on/off	-	Ambient Pressure fault flag	Latched
OUT6.15	fAPo	boolean	on/off	-	other engine's AP fault flag	Latched
OUT6.16	fEQ	boolean	on/off	-	Engine Torque fault flag	Latched
OUT6.17	fEQo	boolean	on/off	-	other Engine's Torque fault flag	Latched
OUT6.18	fESo	boolean	on/off	-	other Engine's Speed fault flag	Latched
OUT6.19	fFFm	boolean	on/off	-	Fuel Flow Measured fault flag	Latched
OUT6.20	fFFp	boolean	on/off	-	Fuel FlowPredicted fault flag	Latched
OUT6.21	fPL	boolean	on/off	-	Power Lever fault flag	Latched
OUT6.24	fOV	boolean	on/off	-	Voltage OR fault flag	Latched
OUT6.25	fBV	boolean	on/off	-	Battery Voltage fault flag	Latched
OUT6.27	fOS	boolean	on/off	-	Overspeed fault flag	Latched
OUT6.28	PL_LATCH	boolean	on/off	-	latch for PL tests	64
OUT6.29	fEsd	boolean	on/off	-	Engine Speed difference test	Latched
OUT6.30	fFFd	boolean	on/off	-	Fuel Flow difference fault flag	Latched
OUT6.31	fOR	boolean	on/off	-	OR test fault flag	Latched
OUT6.32	fAL	boolean	on/off	-	AL fault test flag	Latched

3.9.3. Conditions

This table defines the conditions for a particular application instance. For generic description see the Test Conditions section. The listed conditions define predicates. The refs are used by other tables when referring to test conditions and conditions on actions.

Table 3.9.3.

Ref	Name	Predicate	Description
COND0	never	F	Always disabled
COND1	always	T	Always enabled
COND5.2	starting	INP4.1 & INP4.2 & ¬ INP4.3	START_MODE and LIGHTOFF and not START_ABORT
COND5.3	running	INP4.4 & ¬ INP4.1	RUN_MODE and not START_MODE
COND5.4	stopped	OUT3.7<10 or OUT5.2<50	cPL<10° or cES<50%
COND5.5	not stopped	OUT3.7>=10 or OUT5.2>=50	cPL>=10° or cES>=50%
COND2.6	other idling	OUT3.5>50	cESo>50%
COND2.7	Speed for EQ	OUT5.2>80	cES>80%
COND2.8	Other speed for EQo	OUT3.5>80	cESo>80%
COND5.9	Other ET and EQ	OUT3.8>800 & OUT3.4>40	cETo>800°F and cEQo>40%
COND5.10	speed sensed	INP2.10>30 & INP2.11>30	ESa>30% or ESb >30%
COND4.11	PL upper quadrant	INP2.28=T	PLg=T
COND4.12	PL lower quadrant	INP2.28=F	PLg=F
COND5.13	PL latch reset	INP2.27=F or INP5.2=T	PLi=F or POWERUP
COND4.14	PL latch	OUT6.28=T	PL_LATCH=T
COND5.15	power up, stopped	INP5.2=T & COND5.4	POWERUP=T & COND5.4
COND5.16	PL zero test cond.	INP2.27=F or COND4.14	PLi=F or PL_LATCH=T
COND5.17	PL interlock test cond.	INP2.27=F & COND4.12	PLi=F & PLg=F
COND2.18	no volts speed	INP2.10<5	ESa <5%
COND2.19	alternator speed	INP2.10>90	ESa >90%
COND5.20	engine overspeed	INP2.10>125 & INP2.11>125	ESa> 125% & ESb > 125%
COND5.21	engine overspeed	INP2.10=<125 or INP2.11=<125	ESa =< 125% or ESb =< 125%
COND5.22	no confirmed freeze faults	¬((OUT6.11=T & OUT6.12=T) or (OUT6.14=T & OUT6.15=T) or ((INP5.2=T or OUT6.20=T) & OUT6.19=T) & OUT6.30=T)	not((fESa=T & fESb=T) or (fAP=T & fAPo=T) or ((POWERUP=T or fFFp=T) & fFFm=T) & (fFFd=T))
COND5.23	ESa faulted	OUT6.11=T	fESa:=T
COND5.24	ESa not faulted	OUT6.11=F	fESa:=F
COND5.25	AP faulted	OUT6.14=T	fAP:=T
COND5.26	AP not faulted	OUT6.14=F	fAP:=F
COND5.27	FFm faulted after power up	INP5.2=F & OUT6.19=T	POWERUP=F & fFFm=T
COND5.28	power up or FFm not faulted	INP5.2=T or OUT6.19=F	POWERUP=T or fFFm=F
COND5.29	ESb not faulted	OUT6.12=T	fESb=F
COND5.30	ESb faulted	OUT6.12=F	fESb=T
COND5.31	APo not faulted	OUT6.15=T	fAPo=F
COND5.32	AP faulted	OUT6.15=F	fAPo=T
COND5.33	power up or FFp faulted	INP5.2=T or OUT6.20=T	POWERUP=T or fFFp=T

COND5.34	power up and FFp not faulted	INP5.2=F & OUT6.20=F	POWERUP=F & fFFp=F
COND5.35	All but one ETs failed	card ({ o | o:OUT6.2..OUT6.6 & o=T}) = 1	All but one ET's confirmed failed
COND5.36	All ETs failed	(OUT6.2 =F &..& OUT6.6=F)	All ET's confirmed failed
COND5.37	Not all ETs failed	not (COND5.36)	At least one ET not failed

3.9.4. Confirmation Mechanisms

This table defines the confirmation mechanism and its parameterisation for a particular application instance. For generic description see Test Confirmation section.

Table 3.9.4.

Ref	Name	x inc	y dec	z limit	Description
CONF4.0	immediate	1	1	1	single detection – no confirmation
CONF4.1	fault count 2-1-8	2	1	8	fault counter with bias to confirm
CONF4.2	long fault count	1	1	200	approx 2 sec no bias
CONF5.1	latch debounce	-	-	3	require 3 consecutive to confirm
CONF4.4	fault count 2-1-20	2	1	20	biased fault counter, 10 to confirm
CONF4.5	fault count 2-1-32	2	1	32	biased fault counter, 16 to confirm
CONF4.6	fault count 2-1-80	2	1	80	biased fault counter, 40 to confirm

3.9.5. Magnitude tests

This table defines the magnitude tests and their parameterisation for a particular application instance. For generic description see Types of Test section.

Table 3.9.5.

Ref.	value tested	Name	dir	limit [MAG2]	Freq mS	Condition	Confirm
MAG1.1	INP2.1	ET1	up	1900	24	COND1	CONF4.4
MAG1.2	INP2.1	ET1	lo	-100	24	COND1	CONF4.4
MAG1.3	INP2.2	ET2	up	1900	24	COND1	CONF4.4
MAG1.4	INP2.2	ET2	lo	-100	24	COND1	CONF4.4
MAG1.5	INP2.3	ET3	up	1900	24	COND1	CONF4.4
MAG1.6	INP2.3	ET3	lo	-100	24	COND1	CONF4.4
MAG1.7	INP2.4	ET4	up	1900	24	COND1	CONF4.4
MAG1.8	INP2.4	ET4	lo	-100	24	COND1	CONF4.4
MAG1.9	INP2.5	ET5	up	1900	24	COND1	CONF4.4
MAG1.10	INP2.5	ET5	lo	-100	24	COND1	CONF4.4
MAG1.19	INP2.10	Esa	up	130	24	COND1	CONF4.1
MAG1.20	INP2.10	Esa	lo	10	24	COND5.2	CONF4.1
MAG1.21	INP2.10	Esa	lo	45	24	COND5.3	CONF4.1
MAG1.22	INP2.11	Esb	up	130	24	COND1	CONF4.1
MAG1.23	INP2.11	Esb	lo	10	24	COND5.2	CONF4.1
MAG1.24	INP2.11	Esb	lo	45	24	COND5.3	CONF4.1
MAG1.25	INP2.12	EP	up	200	24	COND1	CONF4.1
MAG1.26	INP2.12	EP	lo	1.5	24	COND5.4	CONF4.1
MAG1.27	INP2.12	EP	lo	1.3*AP	24	COND5.5	CONF4.1
MAG1.28	INP2.13	AP	up	20	24	COND1	CONF4.4
MAG1.29	INP2.13	AP	lo	4	24	COND1	CONF4.4
MAG1.30	INP2.14	Apo	up	20	24	COND1	CONF4.1
MAG1.31	INP214	Apo	lo	4	24	COND2.6	CONF4.1
MAG1.32	INP2.15	EQ	up	140	24	COND1	CONF4.5
MAG1.33	INP2.15	EQ	lo	-10	24	COND2.7	CONF4.5
MAG1.34	INP2.16	Eqo	up	140	24	COND1	CONF4.5

MAG1.35	INP2.16	Eqo	lo	-10	24	COND2.8	CONF4.5
MAG1.36	INP2.17	Eso	up	130	24	COND1	CONF4.1
MAG1.37	INP2.17	Eso	lo	10	24	COND5.9	CONF4.1
MAG1.38	INP2.18	FFm	up	2800	24	COND1	CONF4.1
MAG1.39	INP2.18	FFm	lo	-100	24	COND1	CONF4.1
MAG1.40	INP4.5	FFp	up	2800	24	COND1	CONF4.1
MAG1.41	INP4.5	FFp	lo	-100	24	COND1	CONF4.1
MAG1.42	INP2.20	PLm	up	30	24	COND1	CONF4.1
MAG1.43	INP2.20	PLm	lo	1	24	COND5.16	CONF4.1
MAG1.44	INP2.20	PLm	up	25	24	COND5.17	CONF4.1
MAG1.47	INP2.23	OV	up	40	24	COND1	CONF4.2
MAG1.48	INP2.23	OV	lo	10	24	COND1	CONF4.2
MAG1.49	INP2.24	BV	up	30	24	COND1	CONF4.2
MAG1.50	INP2.24	BV	lo	10	24	COND1	CONF4.2

3.9.6. Rate tests

This table defines the Rate tests for a particular application instance. For generic description see Types of Test section. The tests compare the difference of change in an input value to a limit. The value tested is $|I - I_{-1}|$ where I_{-1} is the previous reading.

Table 3.9.6.

Ref.	value tested		dir	lim	Frq mS	Condition	Confirm
RATE1.1	$\|INP2.10 - INP2.10_{-1}\|$	Esa	Up	100 %/s	48	COND1	CONF4.1
RATE1.2	$\|INP2.13 - INP2.13_{-1}\|$	AP	up	2.6 psia/s	384	COND1	CONF4.1
RATE1.3	$\|INP2.18 - INP2.18_{-1}\|$	FF	up	2880 pph/s	48	COND1	CONF4.1
RATE1.4	$\|INP2.20 - INP2.20_{-1}\|$	PLm	up	15%	64	COND4.14	CONF4.1

3.9.7. Multiple Sensor Tests

This table defines the multiple sensor tests for a particular application instance. For generic description see Types of Test section.

Table 3.9.7.

Ref.	Value tested		Function	dir	lim	Frq mS	Condition	Confirm
MULT1.1	|INP2.10 – INP2.11|	|ESa-ESb|	speed diff.	up	5	48	COND5.10	CONF4.1
PRED1.2	|INP2.18 – INP4.5|	|FF-FFp|	step check	up	20	384	COND1	CONF4.1
MULT1.2	|INP2.12 – INP2.13|	|EP-AP|	EPambient	up	4.5	24	COND5.15	CONF4.1
MULT1.3	INP2.24 – INP2.23	BV-OR	diode short	up	0.2	96	COND2.18	CONF4.6
MULT1.4	INP2.24 – INP2.23	BV-OR	alternator	lo	0	96	COND2.19	CONF4.6

3.9.8. Latch (Pseudo) Tests

These tests do not have a permanent state. I.e. once they confirm a detection they go back to the healthy state and start testing again. They are used for setting/resetting the PL latch when a condition is met and a value has been reached.

Table 3.9.8.

Ref.	Value tested	Function	dir	lim	Frq mS	Condition	Confirm	Action
MAG1.51	PLm	Pllatch set	up	25	48	COND4.11	CONF5.1	OUT6.28=T
MAG1.52	PLm	Pllatch set	up	5	48	COND4.12	CONF5.1	OUT6.28=T
ACT4.16	PLm	Pllatch reset	up	-	48	COND5.13	-	OUT6.28=F

3.9.9. Healthy Actions

This table defines the healthy actions for a particular application instance. For generic description see Test Result Action section.

Table 3.9.9.

Ref.	All these tests must be healthy	Definition	Description	Condition
ACT7.1	MAG1.1, MAG1.2, MAG1.3, MAG1.4, MAG1.5, MAG1.6, MAG1.7, MAG1.8, MAG1.9, MAG1.10	OUT5.1:= median (INP2.1 to INP2.5)	cET:= median (ET1..ET5)	COND1
ACT5.2	MAG1.19, MAG1.20, MAG1.21, MULT1.1, RATE1.1	OUT5.2 := IN2.10	cES:=ESa	COND1
ACT5.3	MAG1.25, MAG1.26, MAG1.27	OUT3.1 := IN2.12	cEP:=EP	COND1
ACT5.4	MAG1.28, MAG1.29, RATE1.2	OUT3.2 := IN2.13	cAP:=AP	COND1
ACT5.5	MAG1.32, MAG1.33	OUT3.3 := IN2.15	cEQ:=EQ	COND1
ACT5.6	MAG1.34, MAG1.35	OUT3.4 := IN2.16	cEQo:= EQo	COND1
ACT5.7	MAG1.36, MAG1.37	OUT3.5 := IN2.17	cESo:= ESo	COND1
ACT5.8	MAG1.38, MAG1.39, PRED1.2, RATE1.3	OUT3.6 := IN2.18	cFF:=FFm	COND1
ACT6.9	MAG1.42, MAG1.43, MAG1.44, RATE1.4	OUT3.7 := IN2.20	cPL:= 30 - PLm	COND4.12
ACT5.10	MAG1.42, MAG1.43, MAG1.44, RATE1.4	OUT3.7 := IN2.20	cPL:= PLm + 30	COND4.11
ACT5.11	-	OUT3.8 := IN2.29	cETo:=ETo	COND1
ACT4.12	-	OUT6.28 := F	PL_LATCH:=F	COND5.13
ACT4.13	-	OUT6.33:=T, OUT6.27:=T	DUMP:=T, fOS:=T	COND5.20
ACT4.14	-	OUT6.33:=F	DUMP:=F	COND5.21
ACT4.15	MULT1.1, MAG1.40, MAG1.41	OUT6.1:=F	FREEZE:=F	COND5.22

3.9.10. Temporary (Unconfirmed Failure) Actions

This table defines the temporary actions for a particular application instance. For generic description see Test Result Action section.

Table 3.9.10.

Ref.	Name	At least one not healthy but none confirmed	Definition	Description	Cond'n
ACT8.1	ET(x) failing	MAG1.1, MAG1.2, MAG1.3, MAG1.4, MAG1.5, MAG1.6, MAG1.7, MAG1.8, MAG1.9, MAG1.10	OUT5.1:= median(healthy (INP2.1 to INP2.5)	cET:= median(healthy (ET1..ET5)	COND 5.37
ACT8.2	ESa failing	MAG1.19, MAG1.20, MAG1.21, RATE1.1	OUT5.2 := lgv(INP2.10)	cES:=ESa^{-1}	COND1
ACT8.3	ESb failing while used	MAG1.22, MAG1.23, MAG1.24	OUT5.2 := lgv(INP2.11)	cES:=ESb^{-1}	COND5.23
ACT8.4	ESb failing, not used	MAG1.22, MAG1.23, MAG1.24	skip	do nothing	COND5.24
ACT8.5	ES diff failing	MULT1.1	OUT5.2 := lgv(INP2.10), OUT6.1:=T	cES:=ESa^{-1}, FREEZE:=T	COND1
ACT8.6	EP failing	MAG1.25, MAG1.26, MAG1.27	OUT3.1 := lgv(INP2.12)	cEP:=EP^{-1}	COND1
ACT8.7	AP failing	MAG1.28, MAG1.29, RATE1.2	OUT3.2 := lgv(INP2.13)	cAP:= AP^{-1}	COND1
ACT8.8	APo failing while used	MAG1.30, MAG1.31	OUT3.2 := lgv(INP2.14)	cAP:= APo^{-1}	COND5.25
ACT8.9	APo failing not used	MAG1.30, MAG1.31	skip	do nothing	COND5.26
ACT8.10	EQ failing	MAG1.32, MAG1.33	OUT3.3 := lgv(INP 2.15)	cEQ:= EQ^{-1}	COND1
ACT8.11	EQo failing	MAG1.34, MAG1.35	OUT3.4 := lgv(INP 2.16)	cEQo:= EQo^{-1}	COND1
ACT8.12	ESo failing	MAG1.36, MAG1.37	OUT3.5 := lgv(INP 2.17)	cESo:= ESo^{-1}	COND1
ACT8.13	FFm failing	MAG1.38, MAG1.39, RATE1.3	OUT3.6 := lgv(INP 2.18)	cFF:= FFm^{-1}	COND1
ACT8.14	FFp failing while used	MAG1.40, MAG1.41,	OUT6.1:=T, OUT3.6 := lgv(INP 6.5)	FREEZE:=T, cFF:=FFp^{-1}	COND5.27
ACT8.15	FFp failing not used	MAG1.40, MAG1.41,	skip	do nothing	COND5.28
ACT8.16	FFd failing	PRED1.2	OUT3.6 := lgv2(INP2.18)	cFF:= FFm^{-2}	COND1
ACT8.17	PL failing	MAG1.42, MAG1.43, MAG1.44, RATE1.4	OUT3.7 := lgv2(OUT3.7)	cPL:= cPL^{-2}	COND1
ACT8.18	OV failing	MAG1.47, MAG1.48	skip	do nothing	COND1
ACT8.19	BV failing	MAG1.49, MAG1.50	skip	do nothing	COND1
ACT8.20	diode short failing	MULT1.3	skip	do nothing	COND1
ACT8.21	alternator failing	MULT1.4	skip	do nothing	COND1

Ref.	Name	At least one not healthy but none confirmed	Definition	Description	Cond'n
ACT8.22	ET failing	(MAG1.1, MAG1.2, MAG1.3, MAG1.4, MAG1.5, MAG1.6, MAG1.7, MAG1.8, MAG1.9, MAG1.10)	OUT6.1:=T,	FREEZE:=T,	COND5.35

3.9.11. Confirmed Failure Actions

This table defines the confirmed failure actions for a particular application instance. For generic description see Test Result Action section.

Table 3.9.11.

Ref.	Name	All these tests must be healthy	At least one confirmed	Definition	Description	Cond'n
ACT13.1	ETx fault		MAG1.1, MAG1.2, MAG1.3, MAG1.4, MAG1.5, MAG1.6, MAG1.7, MAG1.8, MAG1.9, MAG1.10	OUT5.1:= median(healthy (INP2.1 to INP2.5) OUTx:=T Where x is in range 6.2 to 6.6	cET:= median(healthy (ET1..ET5)), fETx:=T	COND5.37
ACT13.2	ESa fault, while ESb ok		MAG1.19, MAG1.20, MAG1.21, RATE1.1	OUT5.2 := IN2.11, OUT6.11:=T	cES:=ESb, fESa:=T	COND5.29
ACT13.3	ESa fault while ESb ko		MAG1.19, MAG1.20, MAG1.21, RATE1.1	OUT6.1:=T, OUT6.11:=T	FREEZE:=T, fESa:=T	COND5.30
ACT13.4	ESb fault		MAG1.22, MAG1.23, MAG1.24	OUT6.12:=T	fESb:=T	COND1
ACT13.5	ES diff fault	MAG1.19, MAG1.20, MAG1.21, RATE1.1, MAG1.22, MAG1.23, MAG1.24	MULT1.1	OUT5.2:= max(INP2.10,INP2.11), OUT6.29:=T	cES:= max(ESa,Esb), fESd:=T	COND1
ACT13.6	EP fault		MAG1.25, MAG1.26, MAG1.27	OUT3.1 := constant, OUT6.12:=T	cEP:=constant, fEP=T	COND1
ACT13.7	AP fault while APo ok		MAG1.28, MAG1.29, RATE1.2	OUT3.2 := IN2.14, OUT6.14:=T	cAP:=APo, fAP=T	COND5.31
ACT13.8	AP fault while APo ko		MAG1.28, MAG1.29, RATE1.2	OUT6.1:=T, OUT6.14:=T	FREEZE:=T, fAP=T	COND5.32
ACT13.9	APo fault		MAG1.30, MAG1.31	OUT6.15:=T	fAPo:=T	COND1

Ref.	Name	All these tests must be healthy	At least one confirmed	Definition	Description	Cond'n
ACT13.10	EQ fault		MAG1.32, MAG1.33	OUT3.3 := constant, OUT6.34:=T, OUT6.16:=T	cEQ:=constant, LOADSHARE:=T, fEQ:=T	COND1
ACT13.11	EQo fault		MAG1.34, MAG1.35	OUT6.34:=T, OUT6.17:= T	LOADSHARE:=T, fEQo:=T	COND1
ACT13.12	ESo fault		MAG1.36, MAG1.37	OUT6.18:=T	fESo:= T	COND1
ACT13.13	FFm fault at powerup or while FFp ko		MAG1.38, MAG1.39, RATE1.3	OUT6.1:=T, OUT6.19:=T,	FREEZE:=T, fFFm:=T	COND5.33
ACT13.14	FFm fault after pwrup & FFp ok		MAG1.38, MAG1.39, RATE1.3	OUT3.6 := IN6.5, OUT6.19:=T,	cFF:=FFp, fFFm:=T	COND5.34
ACT13.15	FFp fault		MAG1.40, MAG1.41	OUT6.20:=T,	fFFp:=T	COND1
ACT13.16	FF diff fault	MAG1.38, MAG1.39, RATE1.3, MAG1.40, MAG1.41,	PRED1.2	OUT6.1:=T, OUT6.30:=T,	FREEZE:=T, fFFd:=T	COND1
ACT13.17	PL fault		MAG1.42, MAG1.43, MAG1.44, RATE1.4	OUT3.7 := lgv2(OUT3.7), OUT6.21:=T,	cPL:= cPL^{-2}, fPL:=T	COND1
ACT13.18	OV fault		MAG1.47, MAG1.48	OUT6.24:=T,	fOV:=T	COND1
ACT13.19	BV fault		MAG1.49, MAG1.50	OUT6.25:=T,	fBV:=T	COND1
ACT13.20	diode short fault		MULT1.3	OUT6.31:=T,	fOR:=T	COND1
ACT13.21	alternator fault		MULT1.4	OUT6.32:=T,	fAL:=T	COND1
ACT8.22	ET failing		(MAG1.1, MAG1.2, MAG1.3, MAG1.4, MAG1.5, MAG1.6, MAG1.7, MAG1.8, MAG1.9, MAG1.10)	OUT6.1:=T,	FREEZE:=T,	COND5.36

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SECTION 4. REQUIREMENTS DOCUMENT FOR CASE STUDY 3: MITA END-TO-END ARCHITECTURE REQUIREMENTS

4.1 Introduction

In this case study we wish to experiment with the construction of applications within given frameworks and architectures which themselves are specified to provide certain kind of fail-safe and dependency facilities.

Traditional methods of constructing such systems either proceed in a monolithic fashion where the domain and architecture are inextricably linked or that the domain and architecture are produced separately, in parallel and often without any linkage to each other. In this latter scenario which we are primarily interested in we will explore the situations where there are mismatches between the architectures and the application being constructed that utilises those architectures. In this situation we will be able to better understand where architectures and applications "break" and what repercussions this has on the overall reliability and dependency properties of the system as a whole.

The role of this document is to outline the requirements process, the plan of work and the initial set of informal (or even semi-formal) requirements for the MITA End-to-End architecture. Additional architectures will be made available during the course of the Rodin project as detailed requirements become available.

The primary concern of this case study is not to produce an application but rather to understand how architectures for applications can be formalised using the techniques being developed inside Rodin.

The rationale of this is that architectures and applications are developed separately and that it is often the case that applications need to be "forced" into certain architectures which compromise certain desirable features of that architecture or application. A relevant concrete example is the addition of security features into existing architectures which can be compromised easily because of the misalignment between the components - this can be seen in some popular operating system environments. This in turn compromises the dependability and fault-tolerance properties of those systems.

The goal is that once an architecture has been formalised this can then be used to assist in understanding the constraints (and its suitability) of that architecture upon any application that utilised that architecture; that is a suite of techniques can be developed to check conformance of an application or additional architecture against that particular architecture. It may also be the case that a notion of conformance needs to be adequately discussed.

In this document we describe the work plan which includes description of the case study components and proposed method, the current case study component requirements and potential alignment and cooperation with other Rodin case studies.

4.2 Work Plan

The case study can be split into a number of phases:

- Construction and Formalisation of E2E Model
- Construction and Formalisation of Security Model
- Mapping of Security Model against E2E Model
- Construction of Simple Application utilising both E2E and Security Concepts

For the E2E and Security framework modelling stages we expect a demonstration of the internal consistency of the models produced.

When mappings the security model against the E2E model we will have a number of options regarding which parts of the E2E should take the responsibility for the various security related functionality. It is also conceivable that the security model and the E2E do not exactly fit - we then need to explore the ramifications of such a situation with regards to the consistencies of the E2E and security models.

Finally the either the construction of a simple application or alignment/integration with out Rodin case studies that utilise both the security and E2E frameworks will be made (in particular Ambient Campus). Again this application itself must be internally consistent and be consistent with the architectures/frameworks employed.

4.2.1 Requirements

We initially define requirements for two systems or architectures:

- MITA
- Security Model

The MITA End-to-End Architectural requirements are described in the document E2E Concepts Reference Model (Ziegler). This document provides the current specification for these concepts.

The security requirements are described later in this document.

Additional architectures will be introduced during the course of this project.

4.2.2 Concept Modelling Process

The first task is therefore to take the initial, unstructured requirements and produce a finalised, structured requirements specification. The process proceeds as shown in figure 1 where we start with some unstructured requirements, proceed with the act of modelling these producing a finalised structured requirements, a dictionary of the concepts and the first conceptual model.

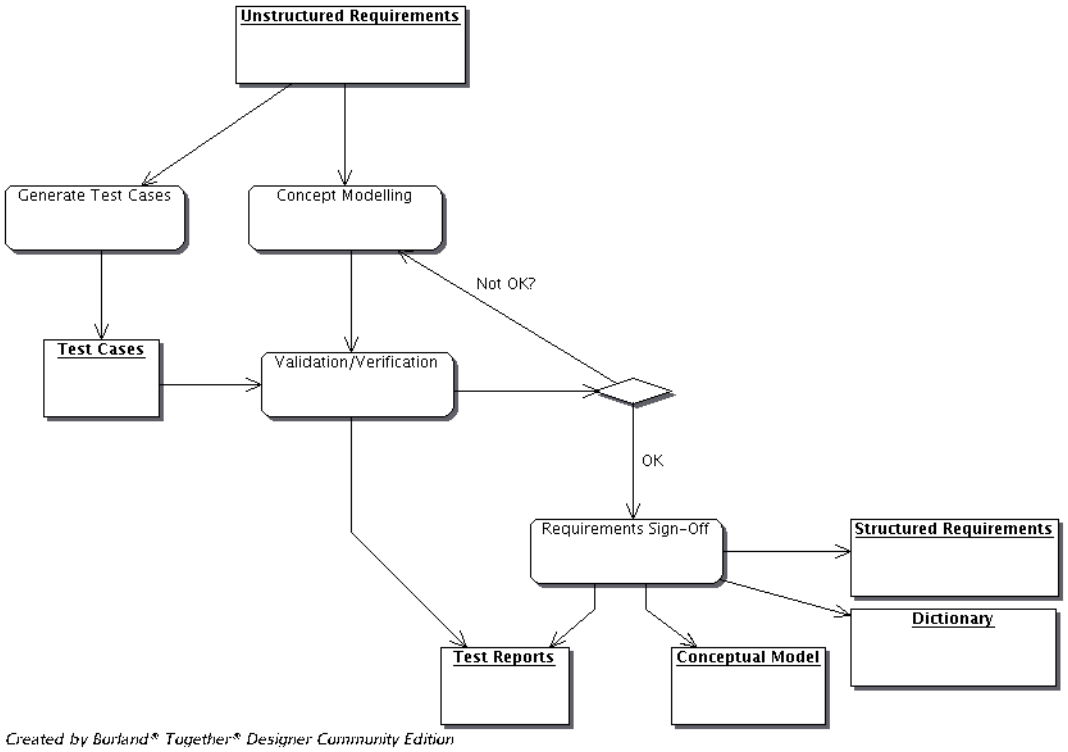

FIGURE 1. Concept Modelling Process

The process is highly iterative and relies upon the transient models produced during this process being validated and checked against the existing unstructured and any structured requirements produced. In a reflexive manner the models produced also act as a validation of the requirements themselves.

Conceptual analysis means that we examine the concepts that we are discovering and decided whether these concepts are relevant and can be well defined. We also check that the concepts are being used consistently between the authors of the requirements and that inconsistencies can be either unified or split so that no ambiguity exists in the concept.

We describe each of the work products, their internal structure and relationships involved in this process. A graphical overview of this is shown in figure 2. Note that we use the ste-

reotype <<work product>> to denote which classes become the deliverables rather than the elements that are contained inside them.

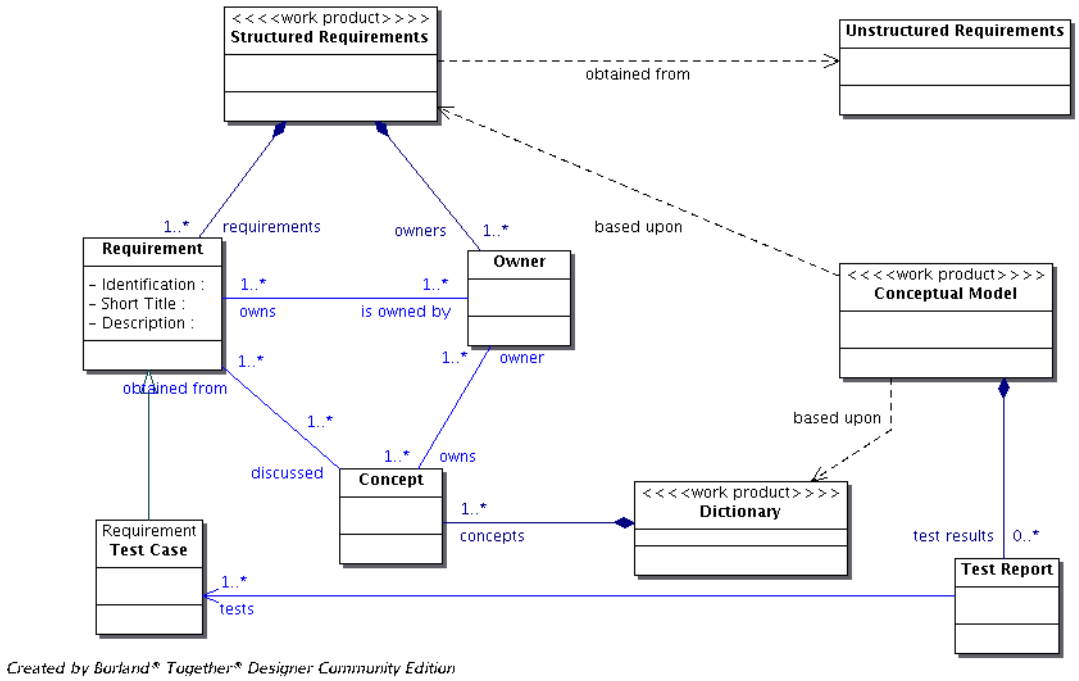

FIGURE 2. Work Product Structure

In figure 2 there are dependency arrows between certain elements. This is to show that those elements do not have a well defined relationship in the usual sense but rather they are to draw attention to that fact that, for example, the structured requirements depends upon the unstructured requirements in some manner and to emphasise the tracing from one set of work products to another.

We consider here that unstructured requirements are provided in the form of a document containing a mixture of text, formulae, use cases and so on. In this form and without "engineering" and validation the elements in this document have no intrinsic, first class modelling value and must not be used directly.

Unstructured requirements can only be used as input to this initial conceptual modelling activity.

The structured requirements contain a list of requirements, a list of owners of those requirements and the test cases. The minimum amount of information held in each requirement is as follows:

- Requirements Identification

This is a number (usually) that uniquely identifies the requirement. No elaborate schema is required here just plain integer numbers.

- Short Title

  A short title to introduce the requirements in a more meaningful way than just a number is required. This must be kept as short as possible and should not contain any information other than is necessary for a title.

- Owner

  The name of the person who is responsible for this requirement. This is necessary so that particular queries about the requirement can be traced back to the person who "invented" that requirements. There can only be one owner for each requirement.

- Description

  This is a short description of that requirement. Requirements must be atomic in nature and not discuss more than one particular topic or aspect.

4.2.3 Test Case

A test case is a description of a test that can be applied to the system to validate some particular piece of (usually) functionality. Test cases may be constructed from use cases or some piece of non-functional information contained in the unstructured requirements.

Note that a test case here is a specialisation of a requirement and similarly a test case discusses certain concepts in the model and has an owner.

Use cases become test cases as we wish to emphasise that in an object oriented system a use case describes a particular scenario related to how the system is going to be used.

Other test cases might be more non-functional in nature and express wishes such as that the system must be theorem proved to ascertain some quality standard. This is particularly the case with safety-critical type systems.

A dictionary contains a list of concepts that are discussed in the structured requirements and are present in the conceptual model. The dictionary during this process serves to identify ambiguous and illdefined concepts.

The dictionary is sorted by the individual definitions it contains and the owners - this allows a concept to appear more than once with more than one owner. If this happens then analysis of the definitions can be made to ensure that the concept is being used by different people consistently.

As we are performing object oriented analysis the conceptual model contains effectively classes and relationships (associations, generalisation/specialisation and so on). Upon the

conceptual model there is a viewpoint that states that any view of this model is made using the UML class diagram.

The conceptual model contains the same concepts as the dictionary but in a graphical form and with more information about their internal structure, invariants across the concepts and taxonomic structures etc.

The conceptual model may include supporting text and documentation to assist in the reading of the model. This text however should not infer more information than is readily accessible from the structured requirements, diagrams in the conceptual model and dictionary together. The primary use of the supporting text is to document invariants, enumeration types etc and their descriptions - those UML elements that tools find so difficult to use.

For each test case there must be evidence of that test case being run against the models produced; in this case the conceptual model contains the evidence that it does adhere to all the test cases in the requirements.

Additional tests such as the results of theorem proving, model checking or other verifications may also be present in addition to the tests cases provided in the requirements.

Also we may consider the generation of metrics from the model a type of test report; these metrics deal with concepts such as class coupling, numbers of attributes/operations per class, inheritance hierarchy depth and so on.

When using metrics, the results given at this stage of modelling contain little information unless they are of extreme values. To give metrics value then it is important that metrics are kept and then compared with other similar projects - do not compare an embedded safety-critical system with a data warehousing project for example. These metrics are also used later in the development process for comparison against other models. Do not use metrics alone as evidence of quality design nor as evidence of the progress of a project. A project with twice as many lines of code is not twice as good, better quality or contains twice as much functionality - more often the reverse is true.

4.3 Ambient Campus

The Rodin CS5 Ambient Campus Case Study has obvious links with this case study. One particularly interesting area is whether the system described in the Ambient Campus Case Study corresponds to the architecture described in the MITA End-to-End Model.

This work will be undertaken later in the course of this project.

4.4 MITA End-to-End Requirements

Internally Nokia promotes a so-called End-to-End (E2E) view that shall comprise all design work related to Mobile Internet services and technologies.

The E2E concepts reference model provides a baseline model for:

- Presenting the E2E architectures with common, defined terms and conventions
- Conducting E2E driven strategic and business analyses with a clear understanding of the relevant architectural concepts
- Analyzing and specifying E2E architectures in a wider context from terminals to servers and peripheral equipment
- Analyzing and specifying E2E architectures in multiple functional layers from applications to middleware and connectivity functionalities

The main target is to provide a baseline for a set of tools for case specific analyses and design documentation. Please notice that the E2E concepts reference model does not provide any universal rule on how to design the details of any particular architecture.

The requirements presented here can be considered as being “unstructured” in nature.

4.4.1 E2E Segments

One way of structuring the E2E environment is done by the concept of E2E Segment. An E2E segment denotes a part of the E2E environment into which the E2E environment can be divided by narrowing to the scope of a class of devices but including anything from hardware over electronics and system software up to general-purpose application software. Any such instance of the concept of E2E Segment is a concept itself. Exactly three instances of the concept of E2E Segment exist. They are called the concept of Server Segment, Mobile Device Segment and Adjacent Device Segment. They are singularities. Each segment separates out a mutually distinct part of the E2E environment.

> *R1: The E2E structure is divided into three segments: server, mobile device and adjacent device*
>
> *R2: Each segment is mutually exclusive*

Note that this division in segments essentially does not promote the E2E view. Each segment covers only a particular slice of the E2E view, but covers anything that contributes to the processing performed in the segment from low-level transmission involved parts to high-level applications interacting with a user.

However, with the help of the segments the "ends" of the E2E view can be made more explicit. In almost any particular instance of an E2E view a mobile device from the mobile device segment takes the end role at one side. This fact makes the mobile device and hence

the mobile device segment central to any E2E view. In some cases the other end is found either in the server or adjacent device segment. In some cases the other end is yet another mobile device, which, of course, belongs to the mobile device segment too.

R3: A physical device may play any particular role (server etc) at any point in time depending upon context.

4.4.2 The Mobile Device Segment

The mobile device segment covers anything closely related to any kind of device that the end user can carry around and physically operate and interact with via certain UI capabilities. The device is able to perform tasks requiring communication.

R5: A mobile device has one or more UI components

R6: A mobile device has one or more communication components (eg: GPRS, GSM etc)

It may use different means for communication depending the situation, but a connection via some kind of mobile network is feasible almost everywhere, even when moving. Any such device is called a mobile device. The mobile phone is the most commonly known mobile device, but the class of mobile devices is not limited to mobile phones. Another such instance is a personal digital assistance device (PDA). Any mobile device existing in the world and any software executed by it is part of the mobile device segment including all communication means any such mobile device has.

4.4.3 The Server Segment

The server segment covers anything closely related to a class of devices commonly called a server because it contributes substantially to the production of a service.

R7: Servers provide services which are used by mobile devices

In most cases the server serves the production of a service in an on request manner.

R8: Services are provided as and when requested by a mobile device

The contribution is the storage and delivery of the content some service(s) is (are) based upon. In other cases the server itself acts actively and issues requests. It is put in charge fetching some particular data from somewhere and processing this data in order that a particular service can be composed.

R9: A server is responsible for the transmission and composition of the results of calling a requested service

A server operates unattended and has enough processing and communication capabilities to communicate with many mobile devices (and other servers) at the same time at satisfactory speed.

R10: A server can handle multiple, concurrent requests

When requested by a mobile device, the server, or more precisely speaking some particular software installed on it for a certain purpose by somebody and continuously executed by it, autonomously responds with the requested data. A significant amount of mobile devices exist that potentially will perform such a request. A server is mostly stationary. It connects with the Inter- or some Intranet or other network via a physically fixed connection. Any server existing in the world and any software executed by it is part of the server segment including all communication means any such server has.

4.4.4 The Adjacent Device Segment

The adjacent device segment covers anything closely related to a kind of device called an adjacent device. Such a device can be in contact with one particular mobile device via at least one sort of data connection for some time. Due to this connection this particular mobile device can make use of the adjacent device for some particular purpose and hence, in a logical sense, the adjacent device is close to this particular mobile device as the term adjacent suggests. Only a small set of mobile devices can get in contact with a particular adjacent device. The preferred, but not limited, way of how a mobile device communicates with an adjacent device is wireless. This connection may be feasible only if the mobile device is physically close enough and equipped with the technical communication means that the adjacent device presumes for this communication purpose.

R10: An adjacent device is one that is physically close to a mobile device

R11: Adjacent devices may themselves be mobile devices

R12: An adjacent device is distinct from a server but might itself provide some kind of services

However, the class of adjacent devices includes also devices that only have some network connection. In this case the mobile device connects to the adjacent device indirectly via mobile network. An adjacent device remains at the same location for at least the time it is performing some task(s) assigned to it. The class of adjacent devices includes many kinds of devices that look differently and perform quite dissimilar tasks. Examples of adjacent device are: a point of sale terminal able to perform a Bluetooth connection with a mobile device; a VCR or set-top-box communicating with the mobile device via some particular wireless proximity connection; the sauna switch with a fixed Internet connection that the mobile device indirectly communicates with via mobile network. Any adjacent device existing in the world and any software executed by it is part of the adjacent device segment including all communication means any such adjacent device has.

4.4.5 E2E Layers

Disparate and in addition to the structuring by segments, the E2E environment is dissected by the concept of E2E Layer. An E2E layer denotes a part of the E2E environment into which the E2E environment can be divided by focusing on the items at a distinct level in the range from hardware over system software up to general-purpose application software but neglecting any natural boundaries between devices. Any such instance of the concept of E2E Layer is a concept itself. Exactly four instances of the concept of E2E Layer exist. They are called the concept of:

- Application Layer
- Enabler Layer
- Driver Layer
- Connectivity Layer

R13: The E2E Architecture is divided into four segments (as described)

The application layer, enabler layer and connectivity layer cover together the E2E environment completely and each of these three layers separates out a mutually distinct part. The part of the E2E environment covered by the connectivity layer superimposes the part identified by the driver layer completely. However, some of the part of the E2E environment covered by the connectivity layer remains outside of the driver layer. In contrast to the segments, each layer keeps the E2E view intact by stretching from E2E.

R14: The E2E segments are distinct and non-overlapping

The application layer covers the processing of the operations and interactions a user performs or the content a user receives. The connectivity layer is devoted to the processing of transmission of data. Anything may be found in here from special wire-based links over any kind of wireless connection up to mobile networks. The so-called enabler layer aims to include what neither is pure and plain transmission nor a direct contribution to the operations or interactions of a user. These layers, and in particular the driver layer, will be described in more detail in the subsequent sections.

4.4.6 Application Layer

This model defines that any item in the application layer is an instance of the concept of Application. In the narrowed scope of this model, an application denotes a unit of software executing in an instance of the concept Mobile Device, Server or Adjacent Device.

R14: Applications execute on mobile or adjacent devices.

If we neglect for a moment all the nuts and bolts of the E2E environment and take a simple holistic view, we can say an application performs some dialog with the end user, which is a process of providing information to and taking input from the end user.

R15: Applications have a dialogue with the user via some UI.

Due to this dialog and directed by it, the executing application (or set of) produces the service the end user desired. All the other stuff of the E2E environment is needed only to make this dialog feasible and to support the delivery of this service.

Any of these applications we prefer to view primarily as an item of the segment it belongs to. They are instances of the concept of Server Application, Mobile Device Application and Adjacent Device Application respectively, which are specializations of the concept of Application.

R16: The concept of application can itself be subdivided as according to the E2E segments

Each of these specialized applications takes the narrowed view of one particular instance of E2E Segment and is executed by an instance of the concept Mobile Device, Server or Adjacent Device respectively. The development work on such an application is done from the point of view of the single segment and for use in a particular device of that segment, hence in a non-E2E view. However, a single project might combine the development of the corresponding applications from different segments in some sort of a super-application approach.

Any mobile device application performs some dialog with the end user by using the particular user interface capabilities of the mobile device. Any server application is able to perform the dialog with the end user only indirectly with the help of a mobile device application dedicated to that purpose.

R17: mobile device applications interact directly with the user via some UI

R18: service applications interact only via an intermediate, for example through the help of some mobile device.

R19: Users do not interact directly with server applications

This mobile device application may or may not contribute to the production of the service(s). In any case, it will make use of the particular user interface capabilities of the mobile device in order to process the dialog originating from the server application. The underlying layers support this processing. In particular the connectivity layer provides some particular data transmission mechanism. The same indirect manner of dialog applies for any adjacent device application.

R20: Users can access applications on adjacent devices only via some intermediate - similar to that of server applications.

However, a server application, and in particular if there is content stored by it, must be installed and maintained by somebody, for instance the so-called service provider. For that

purpose, the server application is able to interact directly with the service provider. Also an adjacent device application may interact directly with a user that is physically close enough to the device. Those local interactions are not in the E2E view and thus not in the scope of this model.

R21: Service Providers may interact directly with server applications

With the logical view of our model in mind we can say that the applications provide services to each other and to the end user. A standard structure for these service relationships and their directions exists. There, the services are labeled anonymously S1 to S5. These labels are placeholders for any real service that might occur between the items connected by the arrow. As you can see, any kind of application serves the end user (S1, S2 and S3). In addition, a mobile device application serves an adjacent device application (S4) and a server application (S5), because the physical provisioning of S1 and S3 requires such services of a mobile device application. S4 and S5 are thus secondary services. Of course, the complete physical performance of such a service requires some processing in the lower layers as well. In particular, the physical device-to-device data transmission occurs in connectivity layer.

R23: All physical device-to-device data transmission occurs in connectivity layer

Of course, the model includes the option that an instance of a particular kind of application serves another instance of the same kind. For instance, a server application may serve another server application.

R24: Server applications may serve other server applications directly.

The two applications may or may not reside in the same device. The model ignores such device boundaries. In particular, a mobile device application executing in one particular device may serve a mobile device application executing in another device. S7 in Figure 7 might represent such a case.

This model defines the concept of Application and its specializations as concepts at meta-level two. Hence, any particular instance of those concepts is a concept itself, but at meta-level one. This fact allows developing models that are based on this reference model and define their own concepts as they go to further detail. An example might be the concept of Game modeled as a particular instance of the concept of Mobile Device Application. Taking further details into account such a model might define some specializations of the concept of Game and only those specializations might become executing objects.

4.4.7 Connectivity and Driver Layer

This model defines that any item in the driver layer is an instance of the concept of Driver. In the narrowed scope of this model, a driver denotes a unit of software executing in an instance of the concept of Mobile Device, Server or Adjacent Device. A particular driver makes a particular device capable to communicate with other devices via a particular data

transmission mechanism. However, in order that communication via this transmission mechanism is finally feasible, this mechanism must actually be available in the connectivity layer too. A driver could be made for and thus requires a physically distinct mechanism, such as Bluetooth.

> *R25:Connectivity drivers provide the communications mechanism, eg: bluetooth*

Another driver, for instance a HTTP stack based one, may include the decision about the data transmission mechanism only in a logical sense and thus defers the decision about the physical means to the parts in the connectivity layer it is actually collaborating with.

This model describes only the general properties of the connectivity layer that is not covered by the driver layer. In that part of the connectivity layer the physical data transmission from device to device takes place. Any kind of data transmission mechanism is potentially used. The choice is limited only by the capabilities of the involved devices and the physical availability of the desired mechanism at the actual point in time and space.

Some transmission mechanisms, such as Bluetooth, require only properly equipped devices with the corresponding driver working in the driver layer in order to connect.

> *R26: Devices (of any kind) have various kinds of communication mechanisms*

> *R27: Certain drivers use certain kinds of communication mechanism*

> *R28: A device can not communicate via a driver if no suitable mechanism for that driver is available on that device*

Other transmission mechanisms, such as mobile network, require in the connectivity layer a lot of additional infrastructure installed and properly working. Such infrastructure stuff can optionally be connected to the Internet and in such a case the Internet might be used to connect to the target device if that is on the Internet too. It shows the standard E2E environment map with examples of specializations of the concept of Driver depending on the data transmission mechanism they support and the segment they belong to. The possible data exchange paths between them are labeled P1 to P4. Notice that P2 definitely and P3 optionally represent communication between two mobile devices.

If a device is equipped with a driver offering only one particular kind of transmission mechanism, this device can communicate with other devices only if this mechanism is actually available in the connectivity layer and this mechanism is also somehow able to connect to the target device. If a device is equipped with a set of drivers each offering another particular transmission mechanism and a few of these mechanisms are actually available in the connectivity layer, this device must select which of them to use either by querying the end user or based on some built-in preferences.

R29: If more than one driver is available then some selection method must be implemented

R30: An ordering of preferences for particular drivers is required

R31: The failure of a driver means that it can be replaced "on-the-fly" if the communications path can be restored between the devices

The concept of Driver is a concept at meta-level two. Any particular instance of the concept of Driver is a concept itself, but at meta-level one. This fact allows developing models that are based on this reference model and define their own concepts as they go to further detail. An example might be a concept of Bluetooth Driver modeled as a particular instance of the concept of Driver. Taking further details into account such a model might define some specializations of the concept of Bluetooth Driver and only those specializations might become executing objects.

4.4.8 Enabler Layer And E2E Service Enabler

Contrary to the other layers, the enabler layer is modeled primarily with the E2E view in mind and thus considers the boundaries of the segments as secondary. The model defines that the item we consider to view in the enabler layer is an instance of the concept of E2E Service Enabler (E2E SE).

4.4.9 Formal Properties of E2E Segments

The concept of E2E Segment and Layer introduce quite many formal properties. These details are more or less obvious for a reader, but must be stated in order to make the model complete and allow further derivations correctly based on stated facts, such as the standard E2E environment map introduced in the subsequent section.

Due to the disparate manner of the definition of the concept of E2E Segment and E2E Layer, any particular layer covers some part of all three segments and any particular segment covers some part of all four layers. Thus, we can say the part of the E2E environment covered by a particular segment and the part covered by a particular layer coincide pair wise and define a subpart common to the particular segment and particular layer

R32: All constituents of the E2E architecture exist as both a segment and layer component

The three subparts in which the driver layer coincides with each of the three segments cover completely and exactly the part of the E2E environment that the connectivity layer has in common with any segment, i.e. the common subparts defined by coinciding the driver layer with the segments are identical with the common subparts defined by coinciding the connectivity layer with the segments. Therefore, the number of common subparts is nine in total and not twelve, as the number of segments multiplied by the number of layers would suggest.

The subparts in which the application, enabler or driver layer coincides with each particular segment cover the application, enabler or driver layer completely and exactly. Or in other words, anything that is part of the application, enabler or driver layer is also part of exactly one particular segment. However, this is not true for the connectivity layer because some of the part of the E2E environment separated out by the connectivity layer is outside of any segment. This is exactly the part of the connectivity layer not superimposed by the driver layer.

Furthermore, the model introduced here implies that for any layer any instance of a device of the classes of devices specified by each of the three segments contains items belonging to that layer. The layers can (and shall) be applied as top-level decomposition of these devices as well. However, any such device covers that part of the connectivity layer only that the driver layer embraces. The other part of the connectivity layer is outside of any such device.

These devices desire to exchange data with each other for the purpose of a service. Such device-to-device data transmission always involves the connectivity layer, because it is the only place where any kind of data transmission mechanism for that purpose resides. For instance all infrastructure of the mobile network is part of the connectivity layer.

R33: All device-to-device communication is made via the connectivity layer.

4.5 Security Architecture

The Security Architecture requirements are at this time not available, however a basic outline of the architecture can be constructed.

Overall the security architecture is considered to be a separate aspect from the design of any application and should be applicable to any application. The security architecture must ensure as automatically as possible that the following objectives as defined in MITA are achieved:

- Integrity

  Prevention of errors or security lapses, eg: modification of information, storage of data and corruption of the system as a whole

- Confidentiality

  Prevention of the unauthorised disclosure of information to a third party.

- Authentication

  Verification of users, security zones, trustworthiness of applications and data.

- Availability

  Prevention of the unauthorised holding of information or resources.

- Intimacy

A user may treat or consider his or her own data as public but the security architecture must prevent disclosure intentionally or unintentionally.

4.6 Base Requirements

S1: All applications will be certified by some authority (for example, VeriSign). This enables the integrity and source of an application to be verified.

S2: Applications communicate via messages. A message might be a data packet over GPRS/GSM, Bluetooth or a coarse grained data packet such as XML (WebServices), SMS, E-mail etc.

S3: The "world" is divided into a number of zones of varying levels of trust and security. Zones may be application based, user based or some other mechanism. It is conceivable that some data/application/etc might exist in any number of zones at any point in time.

S4: Users have different perceptions of trust for each zone. For example, zones which do not process any information but just act as data carries trust all messages while the user's end device will.

S5: Messages or communication which cross zone boundaries must undergo some kind of certification or encryption to ensure that their validity/integrity is upheld.

S6: Messages may not pass between a zone of higher trust and a zone of lower trust without some form of certification and/or encryption.

S7: Users may set up trusted channels of communication between applications in different zones. However this channel would then be restricted to communication between those applications only. This would be achieved by certification of the messages.

S8: A user may reduce their level of trust for any zone at any time. This makes their overall perception of the world more secure.

S9: To increase their level of trust certification or validation of certification must be obtained. It is also possible that a zone's level of trust could be increased but this would entail that any zone communicating directly with it would consider that zone to be less trustworthy.

S10: Any message that appears compromised or does not have a valid certificate will be "sandboxed"

S11 Sandboxes are zones which are completely untrustworthy and can not communicate with any external zone.

S12: Users may share their views of zone security with other users

S13: If two zones are shared then their overall security or trust level is of the lowest

S14: If a zone is unshared then it returns to its original trust status. This might compromise security if that zone then contains uncertified applications or data obtained from other zones originally. In this case the zone's trust returns to the lowest level of trust for any received application or data.

S15: Users may customise access to their zones (see also S12) using certification

S16: The Security Architecture will be implementable within MITA

S17: Authentication may be made via certification, password or other suitable mechanism

S18: "Single Sign-on" must be provided as far a possible

S19: Messages which contain "secure information" (eg: passwords) must be readable only in zones of equal or higher trust level than the information inside the message is destined for.

S20: Messages may be time-stamped and have time dependent levels of trust. For example, a message containing financial results information will be initially secret (to some) but public to all after a certain time.

S21: In user terms, the security of applications and messages must be as transparent as possible and the management of the policies used as automatic as possible

S22: Secure key and certification exchange/distribution must be possible within the architecture

S23: Key and certification exchange/distribution may be implemented by IKE (Internet Key Exchange) where possible (ie: non mobile)

S24: Acknowledgement of receipt (or not) of messages must be possible

S25: Authentication may be made over a number of levels.

Additional requirements will be made available during the course of the project.

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SECTION 5. REQUIREMENTS FOR CASE STUDY 4

1 INTRODUCTION

1.1 Purpose

This document states the requirements for the Civil Aviation Authority's CCF Display Information System, or 'CDIS' and includes requirements traceability.

It is intended that this document will be the starting point for prototyping and detailed specification work to be done during the implementation, and also for the acceptance tests the CAA will use to determine whether the CDIS system meets its requirements.

1.2 Readership

Readers who are unfamiliar with air traffic control concepts will find that chapter 2 provides a fairly comprehensive introduction. Chapter 3 describes the functional requirements. These chapters assume that the reader is already familiar with air traffic control terminology.

1.3 Background

CDIS is one of a number of systems being commissioned by the CAA which go to make up a new super-system for air traffic control in the south east of England called the Central Control Function, or 'CCF'. The main purpose of CCF will be to ensure the safe and orderly arrival and departure of flights to and from airports in the London Terminal Manoeuvring Area, or 'LTMA'.

1.4 Special notations

Various special notations have been used in parts of this document:

- entity relationship diagrams;
- data flow diagrams;

These are described briefly in the document, in the chapters where they are first used. The particular variants of ER and data flow notations used are described in reference [2].

1.5 Structure of this document

Chapters 0 and 1 are document control and introduction respectively.

In chapter 2, we describe the environment in which the CDIS system will operate, using entity relationship diagrams. Chapter 2 forms an essential part of the system specification, and should not be separated from it; readers new to the document intending to understand fully chapters 3 and 4 should start by reading chapter 2.

In chapter 3, we describe the functions of the CDIS system; the chapter starts with a data-flow diagram description of the primary functionality of the CDIS system.

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2 DESCRIPTION OF THE CDIS ENVIRONMENT

The sections in this chapter are as follows:

2.1 Introduction

This chapter describes the environment in which the CDIS system will operate.

2.1.1 How the description is divided up

Because the description is large, we have split it up into a number of **themes**. Each theme is described in a separate section. See the top of the page for the list of themes.

In the chapter we make extensive use of entity-relationship diagramming to document relationships and invariant relations. Each theme's section is arranged as follows:

1. A text overview.
2. An entity relationship diagram which highlights the most important entities in that part of the environment, and documents the relationships between the entities.
3. A text description of each entity, including descriptions of all its attributes; entity and attribute names are in bold type; the text describing the attributes is indented with respect to the entity description.
4. A description of each relation in the diagram; the actual relation is printed in italic type.
5. A list of additional invariant relations which cannot readily be captured in the entity relationship diagram, with accompanying text descriptions.
6. A list of assumptions.
7. A list of questions.

2.1.2 Benefits of describing the environment

Describing the environment of CDIS serves a number of purposes:

1. We aim to specify and implement a system which closely reflects its environment, so that changes in that environment, which lead to changes requested in the CDIS software, are naturally reflected in changes to the corresponding pieces of that software. An understanding of the environment is a prerequisite of such an approach.
2. It provides an accurate picture of the boundary of the CDIS system, which is a vital part of specifying the system. An extensive environmental description has been put together for the whole of the CCF by the MITRE Corporation. This chapter singles out those parts of the environment especially relevant to CDIS, and brings these up to date; it further describes those parts of the CDIS environment made up of other computer systems—. These fall within the boundary of CCF, and so are not described in the MITRE documents.

2.1.3 The system/environment boundary

The environmental model considers the world of air traffic control from the perspective of the CDIS system. Entities such as pages held by CDIS are internal to the system and disregarded by the model. Other entities such as airports or controllers are clearly part of the environment and are included in the CDIS world model. Less obviously, the external computer systems which interface to CDIS also form part of its environment. For a further group of entities which relate to the system's interfaces to the world, a choice must be made whether to class them as world objects or system objects. These entities, which include devices such as display devices, are said to be on the system/environment boundary. In this specification we choose to include peripheral devices in the environmental model.

2.1.4 Understanding Entity relationship diagrams

The entity-relationship diagramming notation is described immediately below. Readers familiar with E-R diagramming should skip the section and continue reading at the start of section 2.2.

Entity relationship diagrams show the relations between objects that are of interest. The objects are called **entities**, and each is represented by a rectangular box on the diagram. Relations between objects are represented by further, lozenge-shaped boxes, connected to the relevant entities by lines. The lines are annotated with numbers, or letters which stand for numbers.

A text description of the diagram's entities and relationships is usually given and the important attributes of each entity described. The range of values relevant to an attribute may also be given; this is referred to as its *domain*. Attributes whose names appear in square brackets are optional.

In the variant of the notation used here, each relation may strictly only be read one way. We have attempted to arrange the diagrams so that the direction of reading is always left-to-right or down the page, though this is not always possible when attempting to avoid crossing lines.

A relation is read as follows: preface the first entity name with 'a', 'can', or 'each'. Next, examine the number on the line immediately adjacent to the second entity; if zero is one of the numbers shown, preface the name of the relation with 'may', otherwise preface it with 'must'. The name of the relation will usually be a verb; where it is not, preface the name with 'be'. Finally, we need to add the second entity in the sentence; if there is a letter on the relevant relation line by it, preface it with 'one or more'; otherwise, preface it with whatever number is there. Make it singular or plural according to the sense.

Practise on the examples shown at the end of this section. In example one, we show a relation between inbound queue and arrival. It should be read as 'An inbound queue may have one or more arrivals'. The 'one or more' corresponds to the letter 'n'; the 'may' to the zero. Example two should be read 'A flight may be controlled by an ATCO'.

Subtyping: sometimes it is useful to differentiate two or more kinds of an entity. The entity (the 'parent') is placed above, and the kinds of it which are to be differentiated are shown below in separate entity boxes, each joined to the parent as shown in example three. A short cross-bar highlights the line to the parent entity. Note that the subtypes are exclusive: if an entity has several subtypes, instances of one of those subtypes cannot also be regarded as one of the other subtypes.

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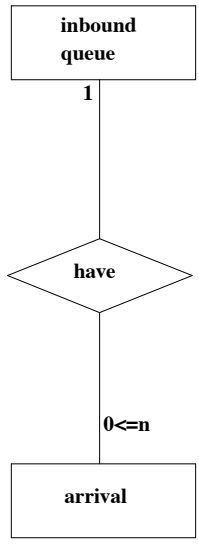
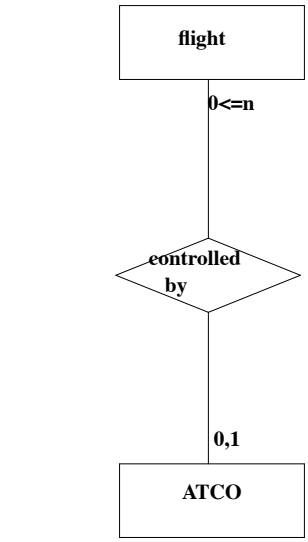
Entity relationship diagrams: examples

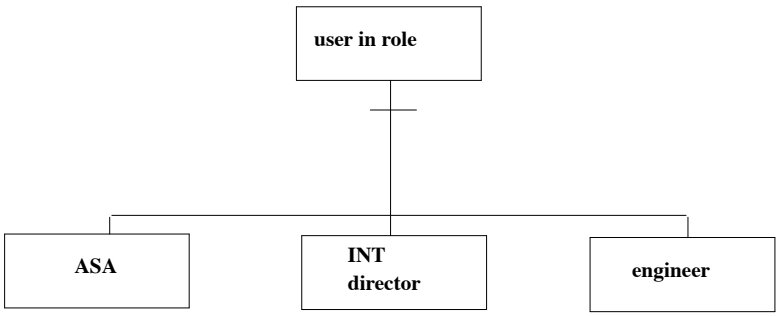
EG 1



EG 2



EG 3



2.2 Data from airports

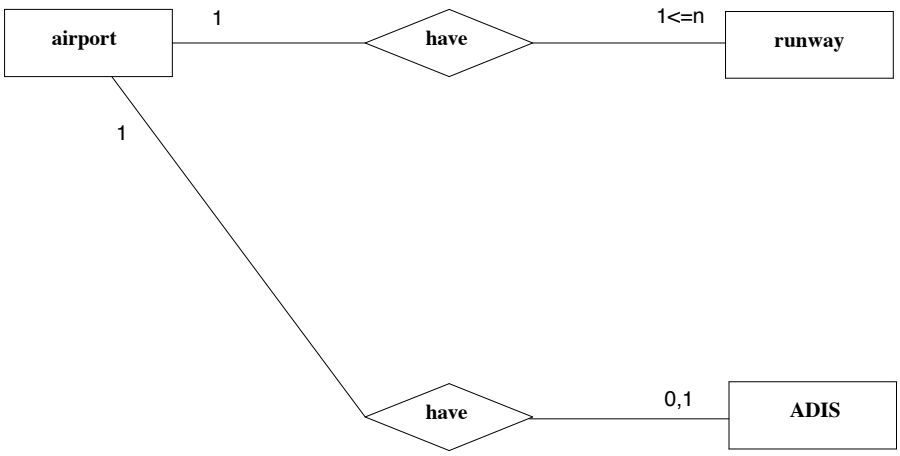
There is a requirement for airport operational information such as meteorological data to be captured and displayed on computer systems at airports and at LATCC. It is proposed that relevant information be stored on Airport Display Information Systems (ADIS), which will be installed at Heathrow, Gatwick, Stansted, and Luton airports.

The ADIS systems will have communications links to NAS and to CDIS. A subset of ADIS information will be held by CDIS and displayed on support information pages, dynamically updated by CDIS from data passed across the CDIS/ADIS interfaces. It will be possible to manually overwrite the airport information from CDIS, though the manually entered values will only remain until the next dynamic ADIS update. Information which has not been updated within a parameter time is marked as old data. If after a further parameter period the data has still not been updated, it is deemed to be out of date. An indication of the status of the data will be shown when the data is displayed. A further possibility is that no value is available for display, as will be the case immediately following an ADIS startup (and initially, during a CDIS startup).

The installation of an ADIS system, is a prerequisite for a **free-flow airport**, ie an airport at which take-off can occur without prior clearance from CCF controllers. For certain airports such as Luton, the presence of an ADIS may still not allow free-flow on all routes, owing to Luton's proximity to Stansted.

Data from airports stored by CDIS includes meteorological information and data concerning each runway at the airport.

2.2.1 Entity relationship diagram



2.2.2 Entity definitions, including attributes

traceunit REQ.ADIS.EN

ADIS

An Airport Information Display System (ADIS) is a computer system for capturing and displaying operational information concerning an airport. ADIS systems are linked to NAS and to CDIS and a subset of the ADIS system information is held on CDIS and dynamically updated via the ADIS/CDIS interfaces. ADIS systems will also be the source of departures information received by CDIS, though the data will normally be routed via NAS.

airport id

An airport has at most one ADIS and therefore the airport id provides a unique identifier for the ADIS entity. This is attribute models the relation: *an ADIS must be owned by one airport*. attribute.

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traceunit REQ.AIRPORT.EN

airport

An airport, or airfield, is the point of departure or destination of a flight. It is the focal point of a control zone and as such always has an associated ATCO called the airfield controller, or tower controller. Larger airports may also be assigned a LATCC final approach approach director, called the FIN, or number two director.

airport id

This attribute uniquely identifies an airport, possibly by using the airport name.

MAC id

The identifier for the MAC which includes the airport. This attribute formalises the relation: *airport is included in MAC*.

domain: same as **MAC.MACid**.

ATIS letter

The Airfield Terminal Information Service (ATIS) letter is used by controllers when giving meteorological information to aircraft. The ATIS letter changes every half hour to the next letter, ie 'b' follows 'a' etc.

meteorological data

This consists of: average, maximum, and minimum wind speed in knots (or the value 'CALM'); average, maximum, and minimum wind direction (in degrees); serial number (alphanumeric); date/time; visibility (Km (?) or free text); cloud (4 values giving OKTAS/height or the single value 'CAVOK'); temperature and dewpoint (numeric or free text); QNH (mbar); QFE (mbar); remarks (free text); metar (free text); time of insertion (free text). Note: 'OKTAS' are eighths of sky covered by cloud; 'CAVOK' indicates: Clear And Visibility OK; QNH is the local sea-level pressure in mbar; QFE is the runway atmospheric pressure in mbar.

traceunit REQ.RUNWAY.EN

runway

An airport has one or more runways, which may be used for arrivals, departures, or both. Heathrow, for example, has two parallel runways which lie East-West. Depending on the wind direction, traffic may land towards East (bearing 270) or towards West (bearing 090). The two runways are distinguished as L(eft) and R(ight). The left runway is called either 09L or 27L according to the direction of traffic flow. Similarly the right runway is called either 09R or 27R.

Heathrow also has a third, shorter runway, lying roughly North-South.

airport id

This attribute identifies the airport served by the runway. Runways are uniquely identified by the airport id and the runway name. This attribute establishes the relationship: *runway is owned by airport*.

runway name

The runway name is based on its direction and position with respect to other runways, eg 27L, 09R. The airport id and runway name uniquely identify the runway.

runway lights

This attributes consists of an on/off status for HIA, SHN, TDZ, CL, SL, SNOW, and PAPI, and an intensity value in the range 1 to 7.

runway status

This attribute defines whether the runway is being used for arrivals, departures, or both.

ILS category

This is a numeric value 1, 2, or 3, which denotes the type of Instrument Landing System (ILS) available on the runway.

IRVR at touchdown

Runway visual range at touchdown in metres.

IRVR at midpoint

Runway visual range at midpoint in metres.

IRVR at stop end

Runway visual range at stop end in metres.

2.2.3 Relation descriptions

traceunit REQ.AIRPORT.RUNWAY

airport to **runway**

An airport must have one or more runways. Note that this does not imply there is always a runway in use. Gatwick, for example, sometimes uses its main taxiway as a second runway when the runway is unavailable for maintenance at night. The inverse relation is: *a runway must be owned by one airport*.

airport to **ADIS**

An airport may have an ADIS. Conversely, *an ADIS must be owned by one airport*.

2.2.4 Additional invariants

traceunit REQ.AIRPORT.ADIS

1. *A free flow airport must have an ADIS (or an equivalent system).*

traceunit REQ.ADIS.NAS_LINK

2. *An ADIS airport has a communications link to NAS.*

2.2.5 Assumptions

1. Runway lights messages are repeated for each runway.
2. There is only one intensity value for each runway covering all the lights.

2.3 Systems related to CDIS

2.3.1 ADIS

The four main LTMA airports will be equipped with new computer systems which will be used to gather operational data about weather, runways, etc., and also about departing flights. These systems are the 'Airport display information systems' or 'ADISs'. They will be equipped with peripherals at the airports, and will be interfaced to the systems at LATCC via the CAA's CAPSIN X25 network. CDIS will receive airport and departure data from each operational ADIS.

The ADIS systems are used to capture and display airport operational information such as meteorological data. A subset of this information will be displayed on CDIS support information pages, dynamically updated from data received via the CDIS/ADIS interfaces.

The installation of an ADIS system, and hence of a link to NAS, is a prerequisite for a **free-flow airport**, ie an airport at which take-off can occur without prior clearance from CCF controllers. For certain airports such as Luton, the presence of an ADIS would still not allow free flow on all routes, owing to its proximity to Stansted.

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2.4 Users of CDIS and their roles

2.4.1 Overview

In this section we describe the various different sorts of role associated with the CDIS system, ranging from air traffic control roles to supporting roles such as the engineering role that encompasses the taking of daily and weekly backups, and maintaining the system. We consider the information CDIS needs to have about the users of the system.

Users are the people who use CDIS. **Roles** are the CDIS-related jobs they perform. The careful separation of 'user' and 'role' may seem somewhat artificial; it is useful because it helps clarify the requirements of the system:

- One user may be simultaneously carrying out more than one role.
- Certain roles, such as page editing, may be being carried out simultaneously by more than one user.
- When expressing system requirements, it is a user acting in a role that is generally of most interest. For example, it is a user acting in a role who enters commands; and whose actions must be checked by the system to confirm that the commands they are inputting are indeed valid for that role (or the system prevents them from ever inputting invalid commands by never offering them in the first place).

The following roles have been identified:

— (TMA) sector controller
— editor
— engineer.

Grouping of Roles

Certain functionality within the system is associated with a group of roles, rather than a single role. We adopt the following role groupings:

ATCO	the TMA sector controller roles
non-ATCO	everyone else
administrator	an editor

The CDIS facilities may be divided up into a number of facility sets; various role groupings then have or do not have access to particular facility sets.

CDIS system security

Security is mainly provided by physical control of user access to the positions.

Roles

Below we identify the major CDIS roles.

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traceunit REQ.ROLE.TMA

TMA

TMA sector controller. There will be five TMA sector controllers in each of the TMA North and TMA South, making 10 TMA sectors in all. CDIS' main function so far as these controllers are concerned will be the provision of pages, and especially the departures and arrivals-sequence pages, as this information is useful to the sector controllers provided it is supplied sufficiently timelily.

traceunit REQ.ROLE.EDITOR

Editor

Data editing staff. A role usually carried out by ATSAs. These staff are responsible for entering the support information pages to the system. They work at user positions specially configured for this purpose.

traceunit REQ.ROLE.ENGINEER

Engineer

The engineers staff the engineer position and system console positions, the former round-the-clock. They carry out all the day-to-day tasks associated with maintaining a running system, including handling removable/consumable media, carrying out backups, carrying out scheduled preventative maintenance, and taking action to restore system services after any failures.

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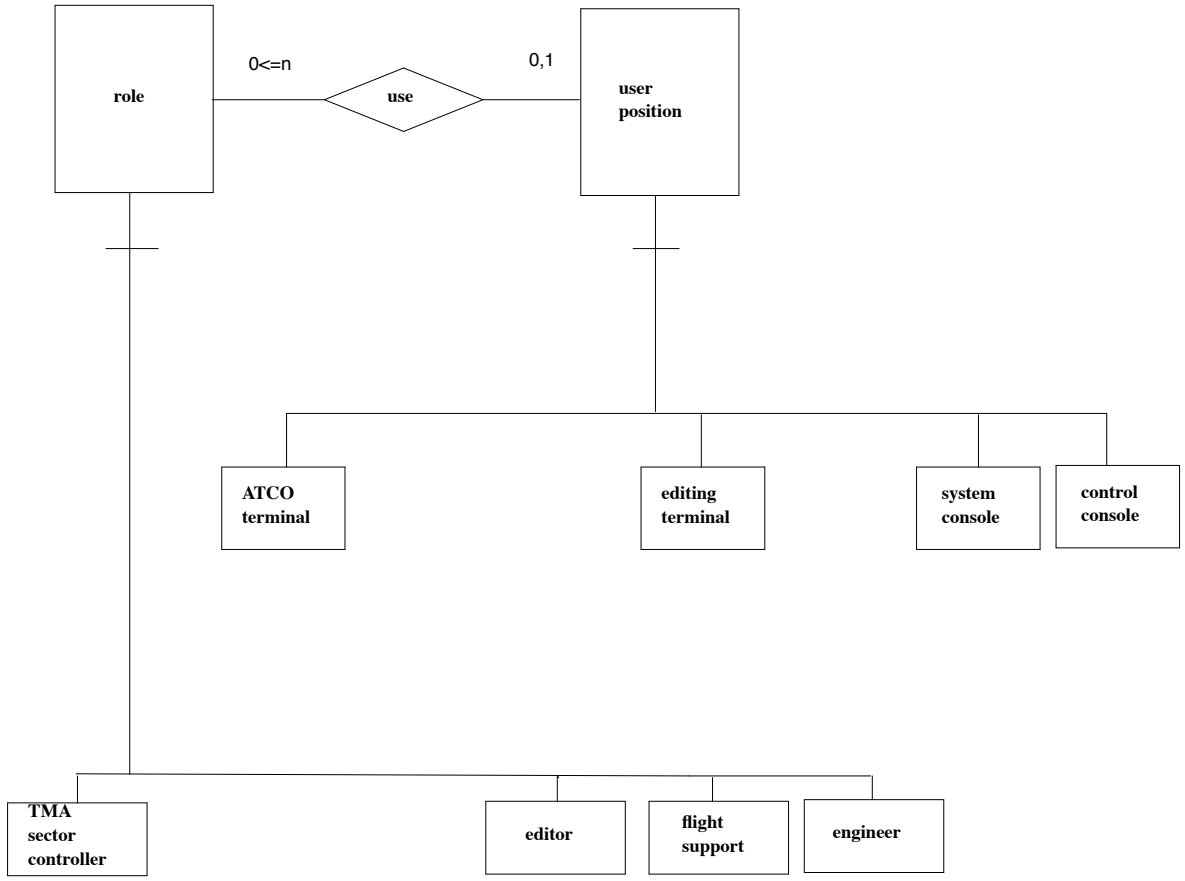
2.4.2 Entity relationship diagram



2.4.3 Entity definitions

traceunit REQ.ROLE.EN

role

Many CDIS roles have been identified. We use the word 'role' to mean a user carrying out a particular job, so there are as many instances of, say, 'engineer' as there are people acting in that role.

role id

Identifies the role.

domain: The roles are as listed in the text overview above.

New roles may well be needed from time to time—see the configuration/adaptation section in

chapter 3.

traceunit REQ.USER_POSN.EN

user position

Any position on CDIS where a user inputs commands to the system, including commands entered on a PSD. Includes all ATCO suites, editing terminals, and engineer terminals.

There is some duplication of equipment required within user positions, and some duplication of positions.

traceunit REQ.ENGINEER.DUPLICATION

The following positions are duplicated for extra reliability:

- engineer position; (the system console is not required to be duplicated, but there should be another console which can carry out the system console role).
  position id

  Identifies the operator station.

The sub-types of user position are listed below:

traceunit REQ.POSN.ATCO

ATCO suite

The standard ATCO furniture suite. The suites are arranged in one of two banks one on each side of the CCF room. An ATCO suite will have at least the following user equipment:

- an EDD, a PSD;

  suite id

  Identifies the suite; used by the supervisors, initially to configure the system, and, later, to reconfigure either for bandboxing or in response to suite failures.

traceunit REQ.POSN.EDITOR

editing terminal

Used by a supervisor or an ATSA to input support information pages and related commands. There will be several editing terminals on the working system.

traceunit REQ.POSN.ENGINEER

engineer position

One is sited in the CCF adjacent to the engineering area, and one in the CDIS CCPS machine area (‘equipment room’). Staffed round-the-clock by engineering staff; however these staff have other responsibilities and a mechanism will be needed to attract their attention to important events.

traceunit REQ.ENGINEER.FUNCTIONS

The engineer’s position will be used for quite a large number of subsidiary system functions, including:

- system (re)start and shut down
- page/TRQ confi guration
- back-ups/restores

traceunit REQ.POSN.SYS_CONSOLE

system console

Essentially a system boot and operating system console. Not staffed round-the-clock. The system console is to support the following functions:

- re-boot system

2.4.4 Relation descriptions

user to **role**

A user may act in one or more roles. Reading the relation the other way,

traceunit REQ.ROLE.USERS

A role may be acted out by one or more users. Certain sector control roles may in the future be conducted by two or three cooperating ATCOs.

role to **user position**

A role may be assigned to a user position. Notice that, since we mean by 'role' a user acting in a given capacity, and since a user can be in only one place at a time, a role can be assigned to at most one user position. The inverse relation is:

traceunit REQ.USER_POSN.ROLES

a user position may be assigned many roles.

2.4.5 Additional invariants

traceunit REQ.ROLE.SUITABLE_POSN

1. Editors must be assigned to their respective terminal types. TMA sector controller roles must be assigned to ATCO terminals. Engineer roles must be assigned to the engineer position.

traceunit REQ.USER.MULTIPLE_ROLES

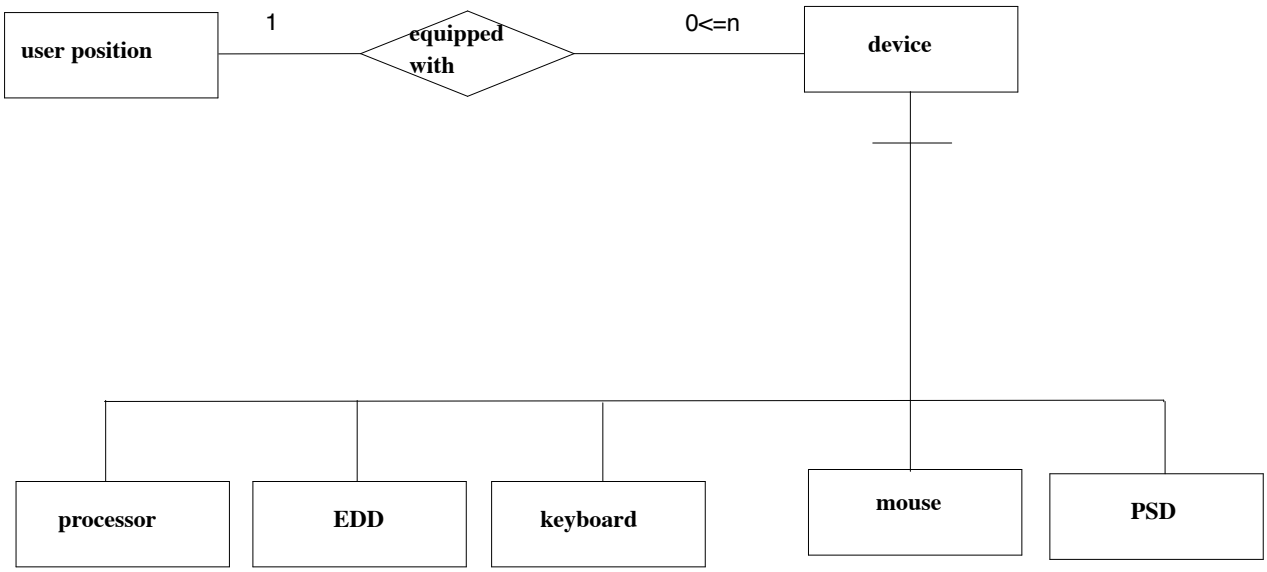
2. If a user is acting in a number of roles, those roles are all assigned to the same user position.

2.5 CDIS devices

2.5.1 Overview

Peripheral devices such as keyboards, and displays are on the boundary between the CDIS environment and the system itself. These devices are sufficiently important to merit inclusion in the CDIS world model. Here we show the kinds of device required by CDIS and describe their relationship to user positions.

2.5.2 Entity relationship diagram



2.5.3 Entity definitions

traceunit REQ.DEVICE.EN

device

This entity includes EDDs, keyboards and PSDs.

device_id

Unique device identifier.

traceunit REQ.PROCESSOR.EN

processor

Each non-console user position will have at least one processor. At certain positions the processor will be duplicated either for reasons of reliability or increased functionality.

traceunit REQ.EDD.EN

EDD

EDDs are used for displaying pages of information. The screen will be divided into a main display area, for full-size pages, and a status area at the bottom, used for viewing broadcast messages.

traceunit REQ.KEYBOARD.EN

keyboard

Keyboards are used for editing purposes.

traceunit REQ.MOUSE.EN

mouse

Mice are used for editing purposes.

traceunit REQ.PSD.EN

PSD

A PSD (Page Selection Device) is a keypad used for selecting pages for display.

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2.5.4 Relation descriptions

user position to **device**

A user position may be equipped with one or more devices. Positions other than console positions have at least a processor.

traceunit REQ.EDD.USER_POSN

Positions other than the system console have at least an EDD. The inverse relation is: *devices may be used at one user position*.

2.5.5 Additional invariants

traceunit REQ.DEVICES.ATCO

1. *ATCO terminals have at least a processor, an EDD, a PSD*.

traceunit REQ.DEVICES.EDITOR

2. *Editing terminals have at least a processor, EDD, keyboard and mouse*.

traceunit REQ.DEVICES.SYS_CONSOLE

3. *The system console has no devices*.

traceunit REQ.DEVICES.ENGINEER

4. *The engineer positions have at least a processor, an EDD, a a mouse and a keyboard.*

We intentionally avoid specifying exact confi gurations, to allow for the possibility of evolution in the way positions are set up for different roles.

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3 FUNCTIONAL REQUIREMENTS FOR CDIS

In this chapter we describe the functions which the CDIS system will perform, including all operations to be offered to users of the system. Considerations of "human factors" and the requirements for the MMI are outside the scope of this study, but are an important part of the work to be done before implementation.

The chapter is divided into the following sections:

- Introduction
- Primary function
- Error & exception handling
- System configuration/adaptation

In the introduction we provide a requirements summary, and give guidance on the Yourdon notation used in other sections. In the primary function section, we describe the primary functions to be provided by CDIS, presented as a levelled set of Yourdon data flow diagrams. The section addresses all normal functioning of each CDIS user and automatic facility.

3.1 Introduction

In this section we state the purpose of the functional requirement, its scope and intended readership, we describe how the requirements were gathered, we give a short summary of the requirement, and an introduction to the Yourdon modelling notation used in the remainder of the chapter. We also explain the tie-up with the environmental modelling of the previous chapter.

3.1.1 Purpose of Functional Requirement

The functional requirement has been put together to:

- be the basis for a fixed price proposal for undertaking the implementation of the CDIS system;
- form the cornerstone of the implementation project. To this end the requirement must:
  - describe the system to be designed and built;
  - form the basis for acceptance testing of the system by the CAA;
  - be the main source of information for the user manuals to be written for the system.

3.1.2 Scope

From the above it is evident that the readers of the requirements specification will have widely differing technical backgrounds. Some difficult decisions have had to be made over what to leave out and what to include in the description.

CDIS is a new system to the CAA—the SIRS system being the nearest thing to CDIS at LATCC to date—so at this stage it is not possible to work out all the uses CAA staff will make of the system, and therefore to identify completely the areas where a degree of flexibility is important. We perceive it as important that a certain amount of time be included in the implementation project for prototyping.

The requirements set out in this document represent our best understanding of the CDIS requirements as presented to us in documents (references [1] to [9] inclusive, and also [12] to [14]) or by members of the CAA CDIS requirements liaison team. The scope of the requirements description in this document has been limited chiefly by lack of time to step through all the

requirements sufficiently thoroughly; but also by lack of fully agreed interface definitions (ICDs) and by inadequate time to carry out prototyping in the area of user interfaces. A substantial amount of detailed specification work remains to be done at the start of the implementation contract.

3.1.3 Short Summary of CDIS Requirement

CDIS is a distributed information, command and control system, with various important ancillary functions. The purpose of CDIS is to aid Air Traffic Control Officers in their control of air traffic, and particularly of arrivals and departures, in the London TMA. CDIS is one of a number of cooperating systems which make up a super-system, the Central Control Function or 'CCF', with this common purpose.

Support Information Pages

Air traffic control officer users of CDIS select pages for viewing on high resolution colour displays. Pages contain text and/or graphical information, some of which may be updated in real time. CAA supervisors and support staff create the pages in isolation from the ATCO part of CDIS using special editor programs provided with the system. Release of pages into the ATCO operational part of CDIS may be delayed, allowing editing of pages to take place days or even weeks in advance.

Airport Data

CDIS receives live feeds of airport data from information systems (ADISs) situated at the free-flow airports Heathrow, Gatwick, Stansted and Luton. This data is displayed on some of the support information pages described above. It is updated in real time; where data is unavailable from an airport, CDIS supervisors/editors may enter airport data manually to the system. Data entered in this fashion is specially highlighted to make users aware that it is not live data.

3.1.4 How the requirements are presented

The primary requirements are presented as a levelled hierarchy of Yourdon data flow diagrams. It is assumed that readers of the document are familiar with the data flow diagram notation.

The bulk of the requirements definition is held at levels 2, 3 and 4 (taking the first breakdown of the context diagram as level 0). Each major level 2 or 3 subsection defining requirements is divided into the following subsection parts:

- a list of principles which underly the system requirements in that area;
- a text overview of the requirement;
- a data flow diagram or diagrams with accompanying text description;

The DFDs provide a process-oriented view of CDIS. It has been possible to model only a fraction of the processes in the limited time available for the study.

3.2 Primary Function

In this section we describe the primary functionality of the CDIS system by means of a levelled set of data flow diagrams, with additional text description. The diagram hierarchy is presented top-down. The description is chiefly process-oriented.

The first two data flow diagrams are simplified overall views of CDIS. The first, the context

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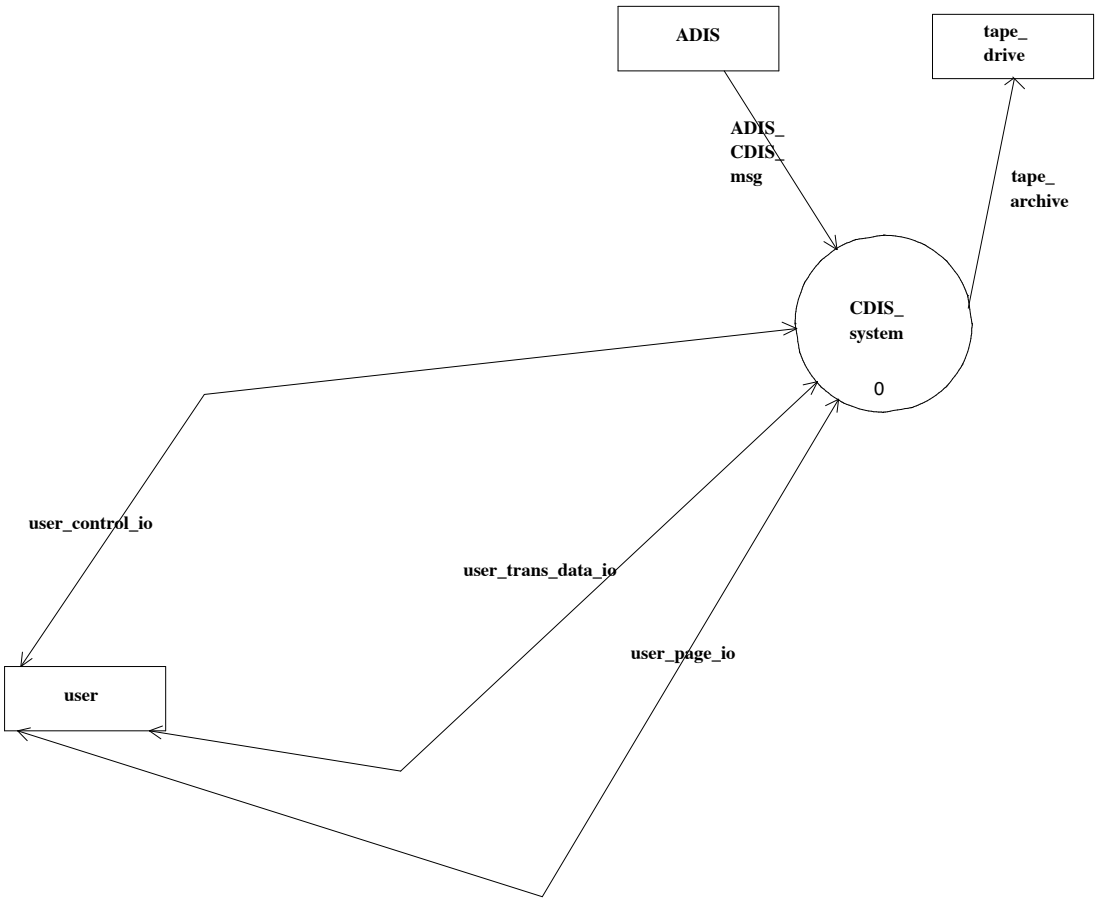
diagram, shows the main flows of data into and out of the system. Apart from the many different types of user command & display input/output, it may be seen that the system also interfaces to other computer systems including ADIS.

Context Diagram



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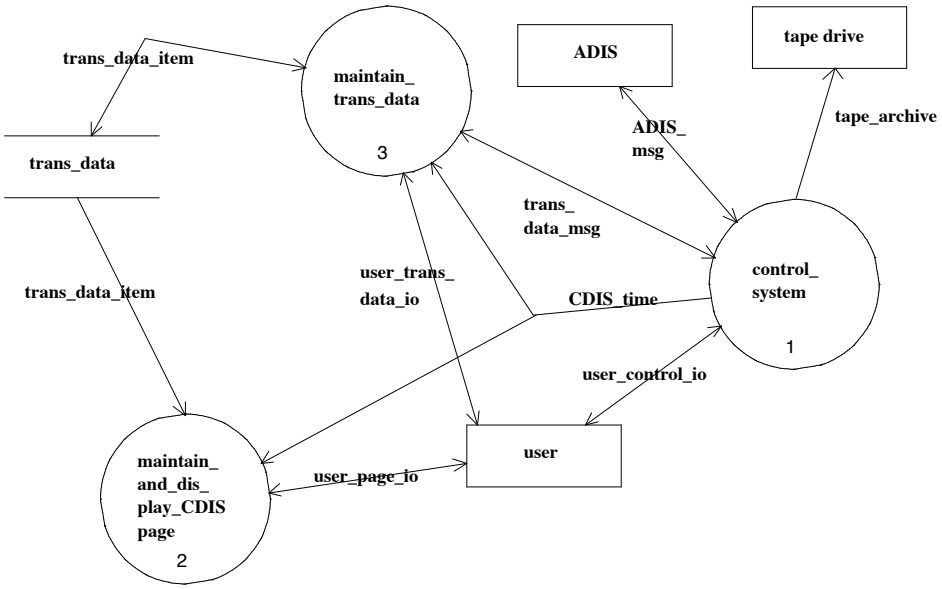
The Level Zero Diagram



In the level zero diagram, we show the main breakdown of description of functionality into three elements:

1. system control;
2. support information page display and editing;
3. the maintenance of transient data;

Only one store is shown at this top level description: the transient data store. This is a piece of system state modifi ed on receipt of *transient data update messages* from NAS or ADIS, and all parts of which may be confi gured into any of the support information pages for display to the users of the system.

The other data fbws are as for the context diagram.

1 Control System

This part of the specifi cation describes many of the ancillary functions offered by CDIS.

Text Overview

Under **engineering_functions** we have gathered together facilities offered the engineer users of CDIS to carry out routine operation and maintenance of the system.

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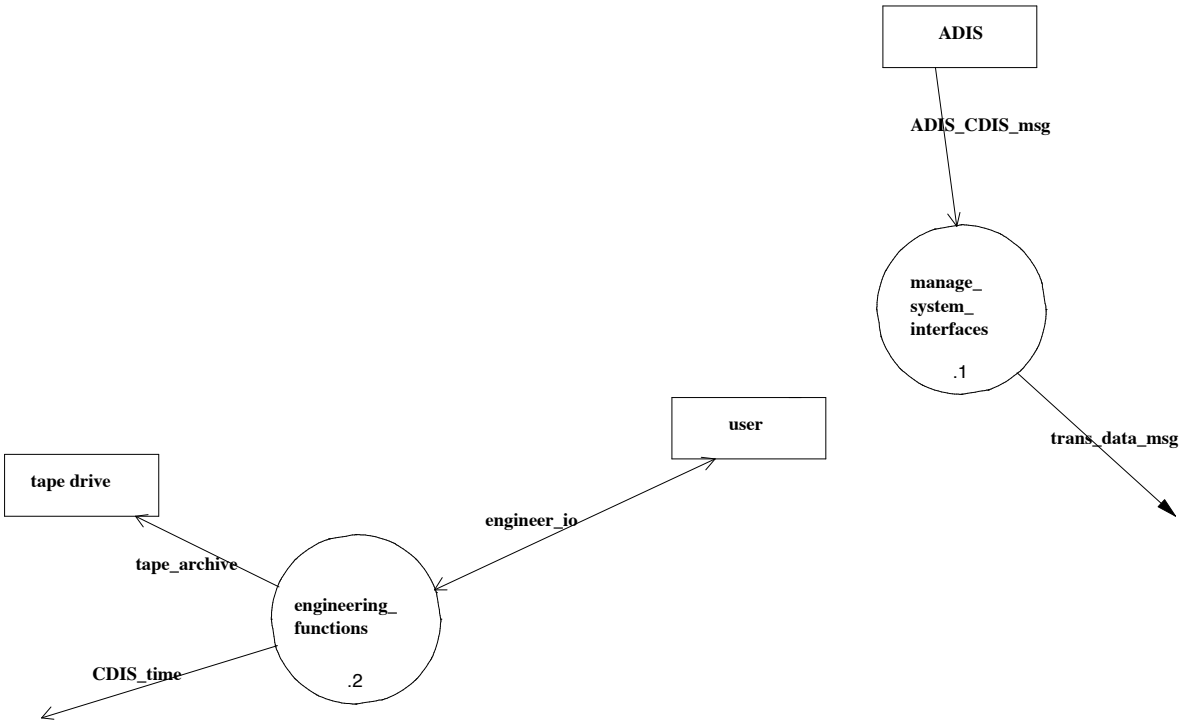
Data flow diagram 1, with description



Process description:

1.1 **manage_system_interfaces**

input/*outputs*:

ADIS_CDIS_msg
Inputs from and outputs to ADIS.

outputs:

trans_data_msg
A processed transient data message updating the CDIS transient data store.

1.2 **engineering_functions**

input/*outputs*:

engineer_io
All engineer user commands and responses.

inputs:

outputs:

CDIS_time
CDIS-internal time distributed to other parts of the system.

tape_archive
System backup archive data to tape.

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1.1 Manage system interfaces

In this sub-section we address the requirements of managing the most important CDIS interfaces, to the various ADIS systems.

Principles

- Detailed non-application-level information will be supplied in separate architecture and design documents. Here we supply only an abstract description of the application layers of the interface.
- Each ADIS supplies CDIS with airport data messages of various kinds.

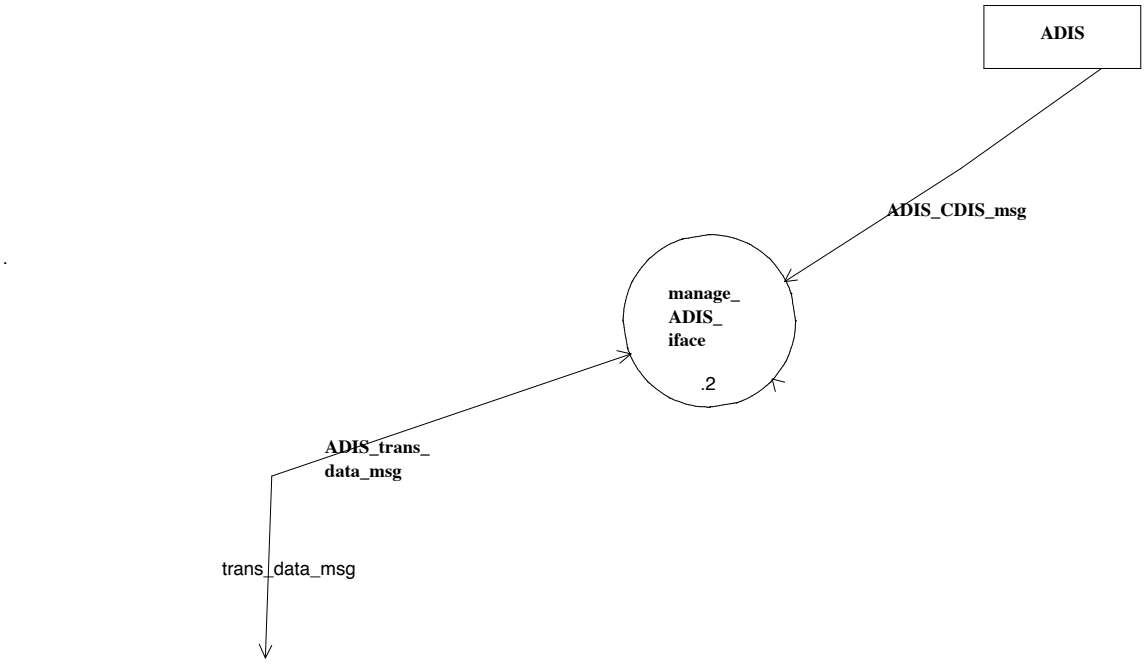
  There are no differences between ADIS systems signifi cant to CDIS. Accordingly, we restrict our attention to an ADIS system assumed to represent any of the actual ADISs.

Text Overview

The ADIS interface forms a major part of the CDIS environment, as described in chapter 2. CDIS receives *transient data* from ADIS, which it stores internally, and which it offers for display on support information pages as confi gured by the page editors and system supervisors.

From the ADIS systems, CDIS receives data about runways and airports, including meteorological data. The full list of messages is given in the ADIS-CDIS ICD [1].

Data flow diagram 1.1 with description



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Process description:

1.1.1 **manage_ADIS_interface**
The process specification for the CDIS side of the CDIS:ADIS interface.

inputs:

ADIS_CDIS_msg

traceunit REQ.SYS_IF.ADIS_CDIS_MSG

The generic input from an ADIS.

outputs:

ADIS_trans_data_msg

traceunit REQ.SYS_IF.ADIS_TRANS_DATA_MSG

Airport data.

The main input from ADIS; transmitted by the interface management software to the airport transient data handling sub-system. Refer to the transient data management description in process 2 for further details on how transient data is handled.

1.2 Engineering functions

Under engineering functions we group together a number of facilities required by the engineer users of CDIS to operate and maintain a fully serviceable system. We define facilities for:

- system start-up and shut-down;
- archive management.

Principles

traceunit REQ.SYS.STARTUP_RAPID

- System start-up/start-over must be very rapid. Only essential functions should be performed during the start-up process.
- Some data are required to be stored on tape:

    i. Backups of all disc-based data (whether this is done using the operating system or the application is not a concern of this specification). Backups are distinguished from archives in that they are always copies of data currently on disc, kept as a safeguard against loss or corruption of the disc-based data. Archives on the other hand are kept to save disc space and the archived material is usually deleted from disc following the copy to tape.

Text Overview

Start up
How the system is initialised to the point where it is in a suitable state to start up the CDIS application (ie power-up, and probably also some separate operating system re-boots) is not specified functionally. This section explains the engineer facilities to start up, start over, and shut down CDIS, given an operational LAN, processor and operating system infrastructure.

traceunit REQ.SYS.INITIAL_STARTUP

Initial start up is carried out at the system console. Start-up and start-over differ:

traceunit REQ.SYS.STARTUP

- Start up of CCPS is divided into cold start and warm start. The only difference is where the state of the CCPS is derived from. Neither kind of start up will preserve transient data. Adaptation can be changed on either kind of start up.
- Cold start, also called start from snap, will involve loading a previously saved snapshot of the CDIS state from a tape. From then on, it will be similar to warm start except for the way out of step PS/2s are treated: while on a warm start PS/2s are not started immediately if their pages are out of date, on a cold start, all healthy PS/2s will be started even if their pages are out of date. The facility will rarely be used, and will probably follow an operating-system re-boot of the whole CDIS processor population.

traceunit REQ.SYS.STARTOVER

- Start up of a workstation will be independent of start up of the CCPS and can be done at any time. If CDIS is running it will automatically be incorporated into the system if it is enabled.
- A warm start will only be possible if CDIS was shut down in good order. It will involve starting from the state immediately before the last shutdown. There will be protection against this being attempted if there was no successful shutdown, for example if CDIS failed. This is necessary because the state of CDIS is not reliable in such circumstances.

Shutdown
Shutdown will be initiated at the control console.

Archive management

Backups

As part of CDIS normal operation, engineers will have to make periodic backups of all data held on disc on the system. No automatic backups will be made.

traceunit REQ.TAPE.NO_OVERWRITE

The system shall check for mounting of already-written tapes, and not overwrite these.

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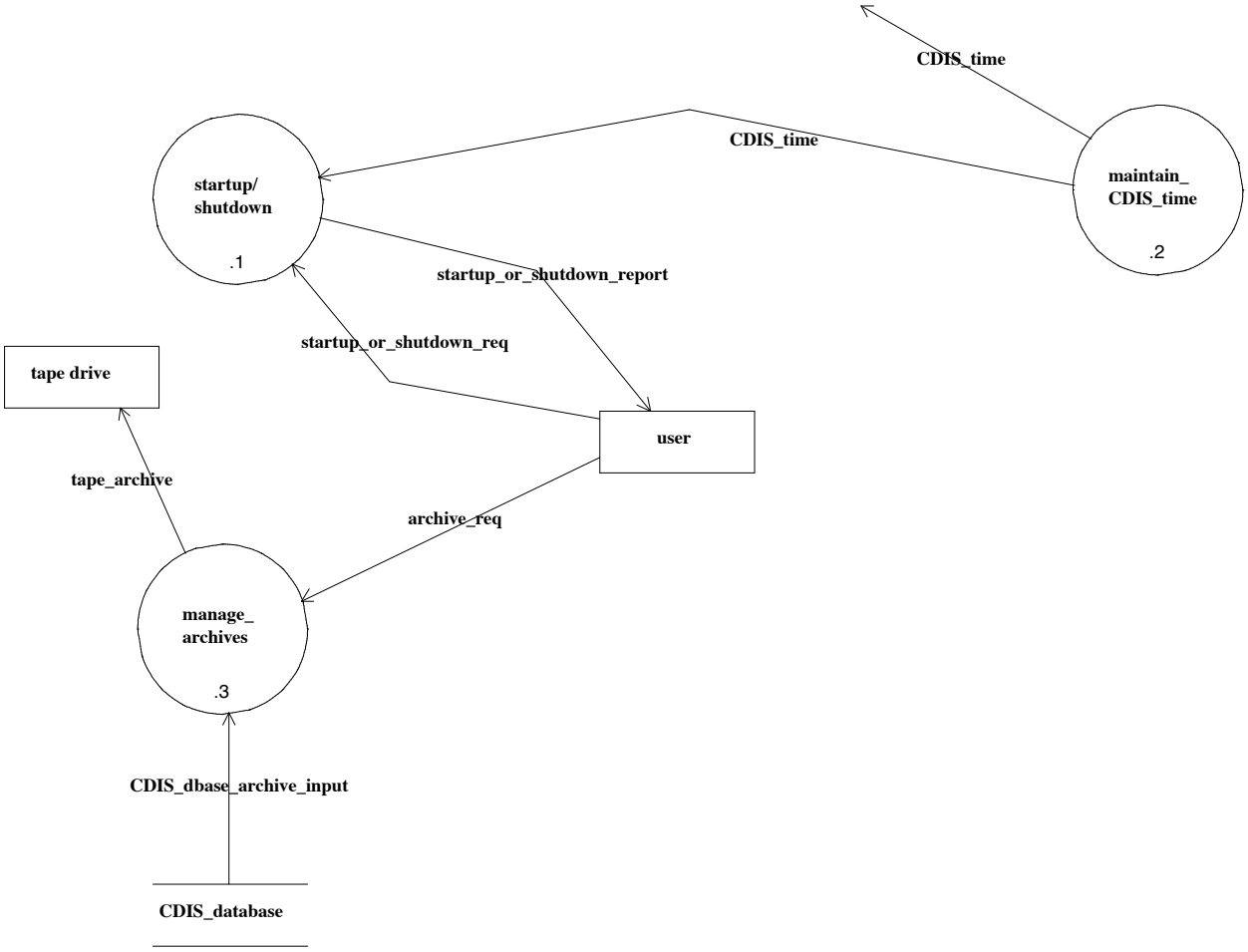
Data flow diagram 1.2 with description



Process specifi cation:

1.2.1 **startup/shut-down**

inputs:

startup_or_shut-down_req
Request by the user to start up, start over, or shut down.

traceunit REQ.SYS.STARTUP_VALID

Start-up invalid unless the system is in a shut-down state.

CDIS_time
Required as input for broadcast and logging purposes.

outputs:

startup_or_shut-down_report
Output about the start-up, start-over or shut-down.

1.2.2 **maintain_CDIS_time**
This process specifies how the system manages time. Details are not relevant to the Rodin subset.

outputs:

CDIS_time
As used throughout the CDIS system.

1.2.3 **manage_archives**
This process specification covers all aspects of managing the archives.

inputs:

archive_req
A backup request issued by the user.

CDIS_dbase_archive_input
State of the database to be saved for a cold start.

outputs:

tape_archive
The archive output to tape.

2 Maintain and display CDIS page

Principles

- Accessing support information is an important, but relatively small part of an ATCO's activity.
- Access to support information should be simple, using as few key strokes as possible.
- Ease of use of the system is more important than flexibility.
- Full page displays are required for certain static information such as maps, but are not required for the various kinds of dynamically updated information.
- Transient data on display is updated in real time as new information becomes available to CDIS.
- It should be possible to display different combinations of departure information, airport information, inbound queue information, and other, static data on a single EDD. This is achieved by using half pages for transient data.
- There are sufficiently few half page combinations that they should be set up by the supervisor, rather than configured by the ATCOs at their suites.
- Scrolling of pages is unacceptable. Where there is too much information for a page or half page, the data should be divided across several pages.
- There is a requirement to edit pages and withhold publication of the new version until a future date. It is not required, however, to hold more than one pending version of a page.

- There is no requirement to share information, other than transient data items, among half pages. Full, split screen pages may, however, share half pages.
- There is a need to use templates for defining transient data pages. The template for transient data, called a layout descriptor, specifies the position and origin of each transient data item and defines a text or graphics background.

Text Overview

One of the primary functions of CDIS is to make readily available to air traffic controllers and their supervisors a variety of textual and graphical information in the form of **pages**, which can be viewed, one at a time, on the display terminal at a control suite.

traceunit REQ.PAGE.VIEW_POSNS

All information pages can be viewed at positions equipped with an EDD and a keypad page selection device (PSD). In addition, all pages can be viewed at editing terminals which are equipped with keyboards.

traceunit REQ.PAGE_EDIT.POSNS

Pages can only be composed or altered at editing terminals, however. The PSD allows all pages to be selected by page number and a subset to be retrieved by fastkey access. There are default fastkey to page mappings defined for each user role which can be redefined by the CCF supervisor.

It is envisaged that the EDD's will display two kinds of page: **full screen pages**, and **split screen pages**. Full screen and split screen pages, will have predefined text or text + graphics contents. The CDIS graphics will support the "free-hand" drawing capability required to draw such things as coastlines.

Split screen pages differ from full screen pages, in that the page is made up from two half page definitions, either two landscape or two portrait half pages.

The information displayed on pages can be categorized as either **fixed data**, also referred to as **static data**, or **transient data**, alternatively called **dynamic data**.

traceunit REQ.PAGE.FIXED_DATA_UPDATE

Fixed data records information which is updated relatively infrequently and always manually.

Transient data on the other hand is normally updated in real-time by CDIS in response to update messages received from other computer systems. The data may be displayed graphically, for example showing a compass rose and pointer to indicate the wind direction at a particular airport. Transient data includes general airport information.

traceunit REQ.TRANSIENT_DATA.AGING

Transient data which is not updated within a parameter time will be marked by CDIS as old data, and after a further parameter period relabelled as out-of-date. This 'ageing' of transient data will be reflected by pages displaying the data.

traceunit REQ.TRANSIENT_DATA.MARK_MANUAL

Items of transient data will also be marked to indicate if their current value was entered manually or if no value is available. Airport operational information, at least, will sometimes be manually overwritten at editing terminals that are assigned the appropriate privilege. It will also be possible to define as transient data, information which is never updated dynamically by CDIS, but only by manual input. This will permit emulation of transient data sources such as an ADIS system.

traceunit REQ.TRANSIENT_DATA.FLAG_CHANGES

There is a requirement for CDIS to be able to flag changes to selected transient data items using, say, inverse video. Particularly important changes, such as changes in atmospheric pressure will need to be flagged and possibly acknowledged by all positions displaying the information (CQF 307). Certain items of meteorological data may need to be flagged if they vary outside a specified range. Flagged data requiring acknowledgment will remain flagged at a console position until acknowledged by all relevant controllers.

Whereas static pages can be edited on-line, dynamic pages must be validated off-line to ensure that no transient data is obscured as a result of using an inappropriate layout definition. Only pages having valid definitions can be released for on-line display.

A valid new page, or a new version of an existing page, can either be released immediately for display or held on a **timed release queue** (TRQ) and made available at a specified date and time. This allows information to be entered well in advance of its required release date, and the page editing workload can be spread over a period of time. Static or dynamic information pages can be held on the queue, dynamic pages becoming active only when released. Full pages or half

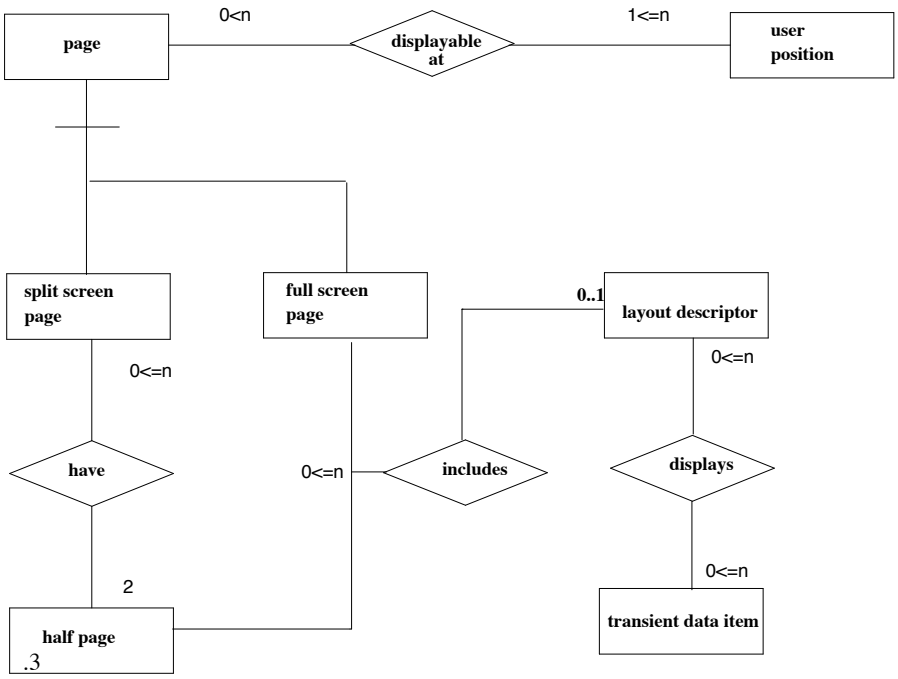
pages can be queued. Only one version of a page may be held on the TRQ.

In general, ATCOs are not informed of the release of new pages, or the update of current pages. However, messages to this effect can be broadcast and displayed in the status area of the screen.

Entity-relationship description

Note that a split screen page is always associated with two half pages.

Entity relationship diagram:



Entity definition, including attributes:

page

CDIS support information may be formatted and displayed on one or more information pages. They are the chief means by which ATCOs access CDIS information. Pages are viewed at terminals whose display area is divided into an upper and a lower logical screen. The upper screen, which occupies most of the viewing area, displays at one time a single page. The lower screen is used to display broadcast messages. A keypad device, called a Page Selection Device (PSD) can be used to select any page for display.

> **page id**
>
> This attributes uniquely identifies a page. Note that the page number does not provide a unique key since there may be several versions of some pages.
>
> *domain*: The domain of this attribute is arbitrary, but could be based on the version and page number.

traceunit REQ.PAGE.NUMBER

page number

Pages are numbered. There may be up to three versions of a page with a given page number: a current version, a backup version, and a version on the timed release queue.

traceunit REQ.PAGE.SELECTION

An ATCO uses his PSD to select by page number the current version for display. The information displayed on a page corresponding to a given number is defi ned by data entry staff or the CCF supervisor.

domain: The natural numbers, starting at 1.

version

traceunit REQ.PAGE.CURRENT_VERSION

For a given page number there is one version of the page available for selection at all display terminals. This is called the **current** version.

traceunit REQ.PAGE.BACKUP_VERSION

There may also be a **backup** version. This is created from a current version when it is edited to create a new version.

traceunit REQ.PAGE.PENDING_VERSION

A third possible version of a page is referred to as **pending**. A page can be edited, then held as pending on the **Timed Release Queue** (TRQ).

traceunit REQ.PAGE.TRQ_RELEASE

The current and backup versions are unchanged until, at a preset date and time, the current version becomes the new backup and the pending version is removed from the TRQ to become the new current version. Note that it is possible for all three versions of a page to exist at once.

traceunit REQ.PAGE.UNIQUE_ID

A page is uniquely identified by its **page number** and **version** attributes.

traceunit REQ.PAGE.VERSION

domain: The page version may be current, backup, or pending.

[release date]

traceunit REQ.PAGE.RELEASE_DATE

The release date attribute specifies the time and date for a pending page to be removed from the TRQ to become the new current page.

domain: This attribute consists of a date and a time, or the value **null** for pages not on the TRQ. Under normal circumstances the date will be a later date than the current system date.

full screen page

traceunit REQ.PAGE_TYPE.FULL_SCREEN

page id

The unique page identifier is as described for **page.page id**.

page number

The page number is as described for **page.page id**.

fixed data

This attribute specifies the data to be displayed.

traceunit REQ.PAGE.FIXED_DATA

domain: Fixed data may be text-only data, or graphics with text. Text data may use a number of fonts, inverse video, double height or flashing characters, underlining, reveal/conceal.

half page

traceunit REQ.PAGE_TYPE.HALF_PAGE

A half page occupies half of the main screen area of an EDD, and may divide the display either vertically (portrait format) or horizontally (landscape format). Two portrait half pages, or two landscape half pages may appear on a split screen page.

traceunit REQ.HALF_PAGE.CONTENTS

A half page may contain text or text and graphics fixed data, or alternatively text or text and graphics transient data formatted according to a layout descriptor.

traceunit REQ.HALF_PAGE.UNIQUE_ID

half page id

Each half page has a unique identifier.

domain: arbitrary

traceunit REQ.HALF_PAGE.ORIENTATION

orientation

The orientation of a half page can be either **landscape** or **portrait**.

domain: landscape or portrait

traceunit REQ.HALF_PAGE.VERSION

version

A half page can be a current, backup, or pending version, as described for **page.version**.

traceunit REQ.HALF_PAGE.RELEASE_DATE

[release date]

Same as **page.[release date]**

split screen page

traceunit REQ.PAGE_TYPE.SPLIT_SCREEN

A split screen page is the same size as a full screen page, but splits the page either vertically or horizontally, and uses half page definitions to define separately the content and layout of each part. A static half page may be set up to display fixed data shown on other half pages. A half page containing transient information uses a layout which can be shared across many pages. Similarly the transient data formatted by the layout may appear on several pages.

page id

Each split screen page has a unique identifier. This is the same as described for **page.page id**.

first half page

This is a reference to a half page which describes the content of the upper half page or left half page, depending on the chosen layout, whether landscape or portrait. This attribute

may contain text or text with graphics fixed data, or alternatively a text or text with graphics layout description for transient data and references to data items to be displayed. Transient data half pages must be created off-line and only released on-line following verification that the layout displays the data as intended.

domain: Either fixed data or references to transient data items and a layout descriptor.

second half page

The second half page defines the content of the lower half page or right half page, depending on the chosen layout, whether landscape or portrait. See description of **split screen page.first half page**.

traceunit REQ.SPLIT_SCREEN_PAGE.RELEASE_DATE

[release date]

Same as **full screen page.[release date]**

traceunit REQ.SPLIT_SCREEN_PAGE.VERSION

version

Same as **full screen page.version**

layout descriptor

traceunit REQ.PAGE.LAYOUT_DESCRIPTOR

This entity describes a format for displaying transient data items on a page. It defines the data positions and a text or graphics and text background.

traceunit REQ.PAGE.LAYOUT_DESCRIPTOR_USE

A given layout may be used by several page descriptions.

traceunit REQ.PAGE.TRANSIENT_DATA

The transient data to be displayed may be specified by the layout itself, or by the page description which uses the layout, or by a mix of these methods.

traceunit REQ.PAGE.TRANSIENT_VERIFICATION

Page descriptions containing transient data must be created off-line and released on-line following verification that the layout displays the data as intended.

layout id

This attribute uniquely identifies the layout.

domain: Arbitrary.

orientation

The layout can be either for portrait or a landscape half pages or for a full page.

transient data item

traceunit REQ.TRANSIENT_DATA.DEF

A transient data item is any item of information held by CDIS which is updated in real-time. Included in airport information is data relating to runways and meteorological information.

traceunit REQ.TRANSIENT_DATA.ID

transient data id

Transient data items could be identified by a name and a source. The name would reflect the kind of data involved, for example callsign, wind direction, or approach sequence number. The source would indicate the flight or airport (and possibly runway) to which the data relates.

domain: A record consisting of name and source identifiers.

[value]

This attribute indicates the current value of the data item, if a value has been assigned. *domain*: A natural number, real number, free text, or **null**.

[manually entered]

Transient data from airports, ie airport operational information, must be marked to indicate whether the current value has been manually entered.

domain: Boolean for airport information; **null** for flight data or approach sequence data.

[last update]

This attribute indicates when airport information or departures information was last updated, allowing old information to be marked as out of date.

domain: A date and time for airport information; **null** for flight data or approach sequence data.

user position

See entity definition in section 2.9.

Relation descriptions

layout descriptor to **transient data item**

traceunit REQ.TRANSIENT_DATA.MULTIPLE_LAYOUTS

A half page layout descriptor may reference many transient data items. Conversely, *a transient data item may be referenced by many layout descriptors*.

page to **user position**

A page must be displayable at one or more user positions. Conversely, *there may be many pages which can be displayed at a user position*. In fact, *all* pages must be displayable at *all* user positions.

split screen page to **half page**

A split screen page must comprise two half pages.

traceunit REQ.HALF_PAGE.MULTIPLE_USE

The inverse relation is: *a half page may appear on many split screen pages*.

full screen page or **half page** to **layout descriptor**

traceunit REQ.TRANSIENT_DATA.MULTIPLE_PAGES

A a full screen page or a half page may use one layout descriptor. Conversely, *a half page layout may format many transient data pages*.

3.2.1 Invariant properties

traceunit REQ.PAGE.NOT_SYS_CONSOLE

1. *Pages cannot be displayed at the system console*.

traceunit REQ.PAGE.VERSIONS_OK

2. *If there exists a backup version of a page, there also exists a current version*.

traceunit REQ.TRQ.RELEASE_DATE

3. *A release date must be specified for a page whose version is* **pending** (ie the page is on the TRQ).

traceunit REQ.TRQ.MAX_FUTURE

4. *The release date for a page is never more than 32 days later than the current (ie system) date*.
5. *A split screen page comprises either two portrait half pages, or two landscape half pages*.

traceunit REQ.HALF_PAGE.LAYOUT_ORIENTATION

6. *A transient data half page and its layout are either both portrait or both landscape format.*

traceunit REQ.HALF_PAGE.CONSISTENT_LAYOUT

7. *The layout descriptor for a transient data half page must be consistent with the referenced transient data items, ie it must define a valid format for each item.*

3.2.2 Assumptions

1. There can be TRQ or backup versions of half pages.
2. A half page can be edited whether or not it is referenced by other pages.
3. At least airport information can be manually updated on-line.
4. Pages can be displayed at the Engineer's position but not at the system console.

Data flow diagram 2 with description

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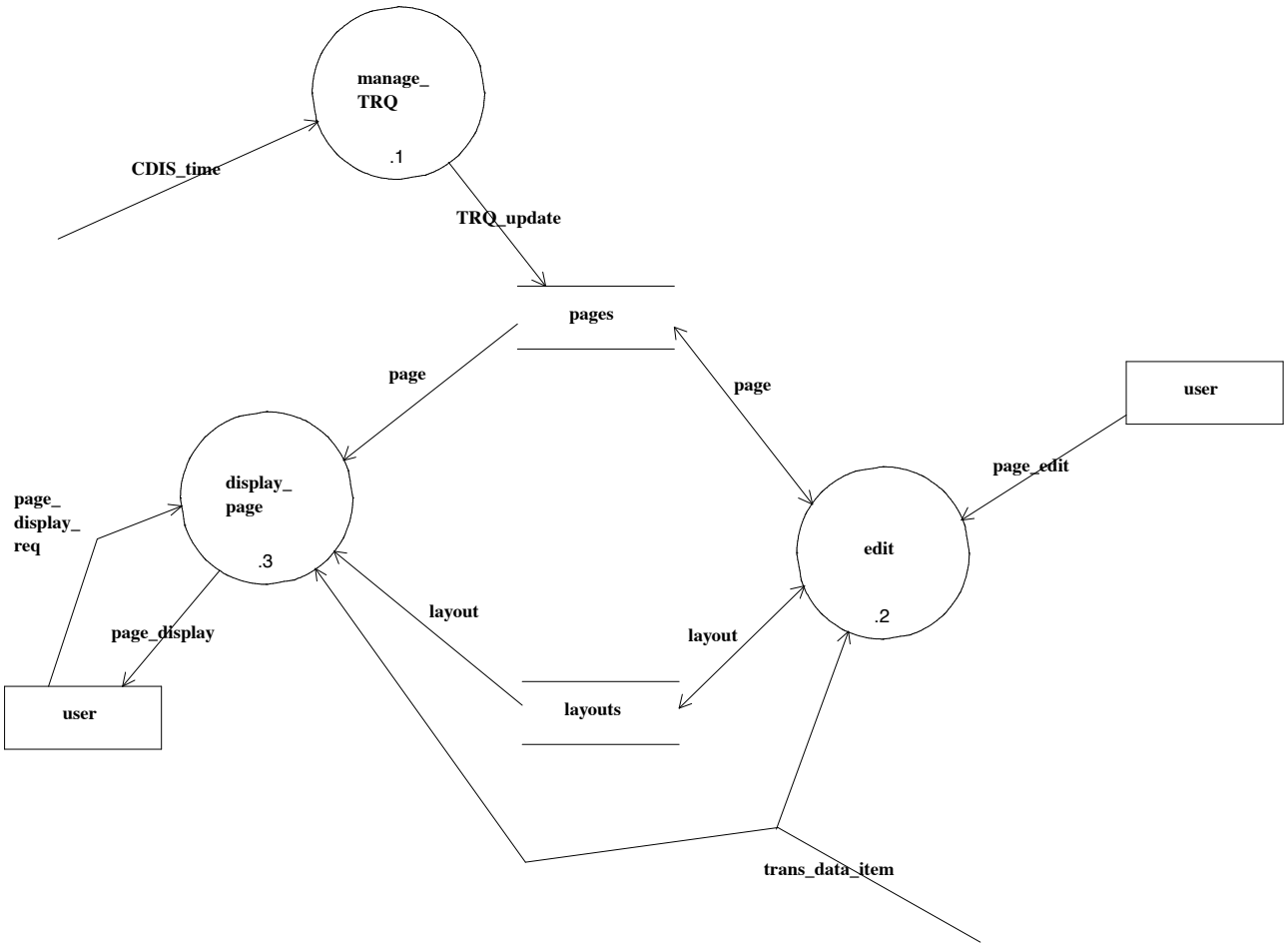

Data flow diagram description:

2.1 **manage_TRQ**

inputs:

CDIS_time
To time queue releases.

outputs:

TRQ_update
The time release queue updates to the pages database. On release of a TRQ page, the current page becomes the reserve; the old reserve page is lost; and the TRQ version of the page becomes the current page.

2.2 **edit**

input/outputs:

page
The page being edited; TRQ, current or reserve versions may all be updated as a consequence of user edits supported by this process.

traceunit REQ.PAGE_EDIT.VERSION

The user may edit the current or the TRQ versions.

traceunit REQ.PAGE_EDIT.LAYOUT

layout
The user may edit a layout.

inputs:

page_edit
The editor interface offered the user.

trans_data_item
Required as input to allow page display.

2.3 **display_page**

inputs:

page
Read from the page database.

layout
As used to build up displays of pages which use some transient data.

trans_data_item
As required to prepare for display pages containing one or more transient data items.

page_display_req
Input by the user requesting that a particular page be displayed at the user position.

outputs:

page_display
The page displayed at the user position.

3 Maintain transient data

In this section we describe the facilities to update, maintain and display so-called 'transient data'; that is, data received from other CCF systems which is to be maintained and displayed in real-time by CDIS on certain of the display information pages.

Principles

- Transient data is automatically maintained by CDIS in response to update messages received from other systems.
- All transient data can be displayed on pages.
- CDIS should be able to display information which is updated in real-time, either in response to an update message received from another system, or in response to manual entry of information.
- The most important kinds of automatically updated information are airport operational data .
- CDIS must allow certain transient data to be maintained manually by editing staff. It should be possible to manually enter transient data values to emulate an ADIS system for airports such as Luton which may not be connected to CDIS.

Text Overview

CDIS receives regular updates of certain special types of data from the ADIS systems by means of asynchronous messages across the CDIS:ADIS interfaces.

This is some of the main operational data needed by the ATCOs in performing the ATCO roles. It includes data about airports, including met and runway data.

This data is expected to be configured for display on a number of (particularly half-size) CDIS support information pages. Generally, users of CDIS may configure any page to show a number of 'dynamic' or 'transient' fields, each linked to one of the transient data values, and each, when the relevant page is being displayed, updated in real time.

Certain attributes of transient data reception and storage are to be configurable/adaptable; refer to the separate section in chapter 3.

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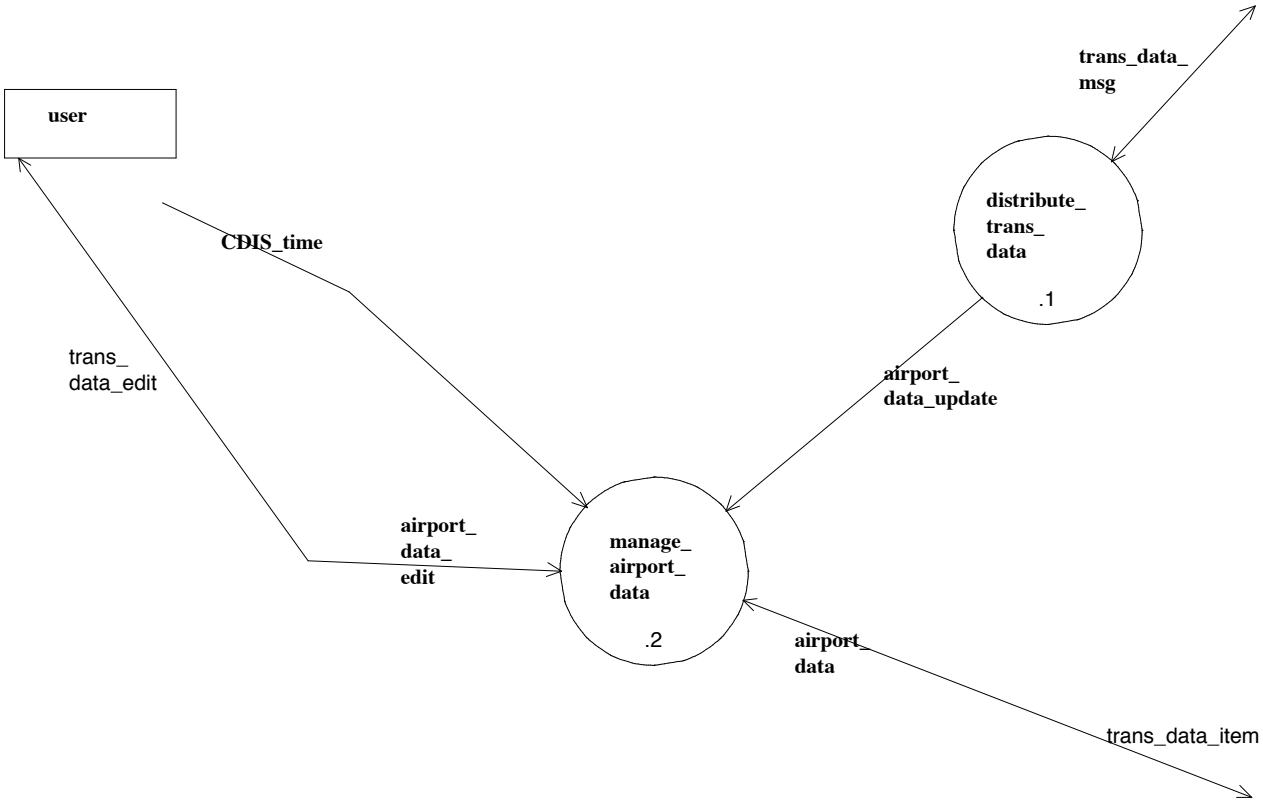
Data flow diagram 3 with description



Process specification:

The process specification is divided into two parts:

- management of user-defined data;
- management of airport data.

3.1 **distribute_trans_data**
Distribution of transient data to/from external systems (ADIS).

input/outputs

trans_data_msg
Message received from the manage system interfaces process

outputs

airport_data_update
Met, runway, etc. data.

3.2 **manage_airport_data**
Airport data management; includes met and runway data, and ageing of airport data; also substitute airport data input by the users.

inputs

airport_data_update
See above.

CDIS_time
Airport data has to be aged.

input/outputs

airport_data_edit

traceunit REQ.AIRPORT_DATA.ALLOWED_USER_UPDATE

Editing of the airport data by the user; for use when an ADIS is unavailable for some reason, or some of its data is not available via the ADIS-CDIS link.

airport_data
Updates to the transient database.

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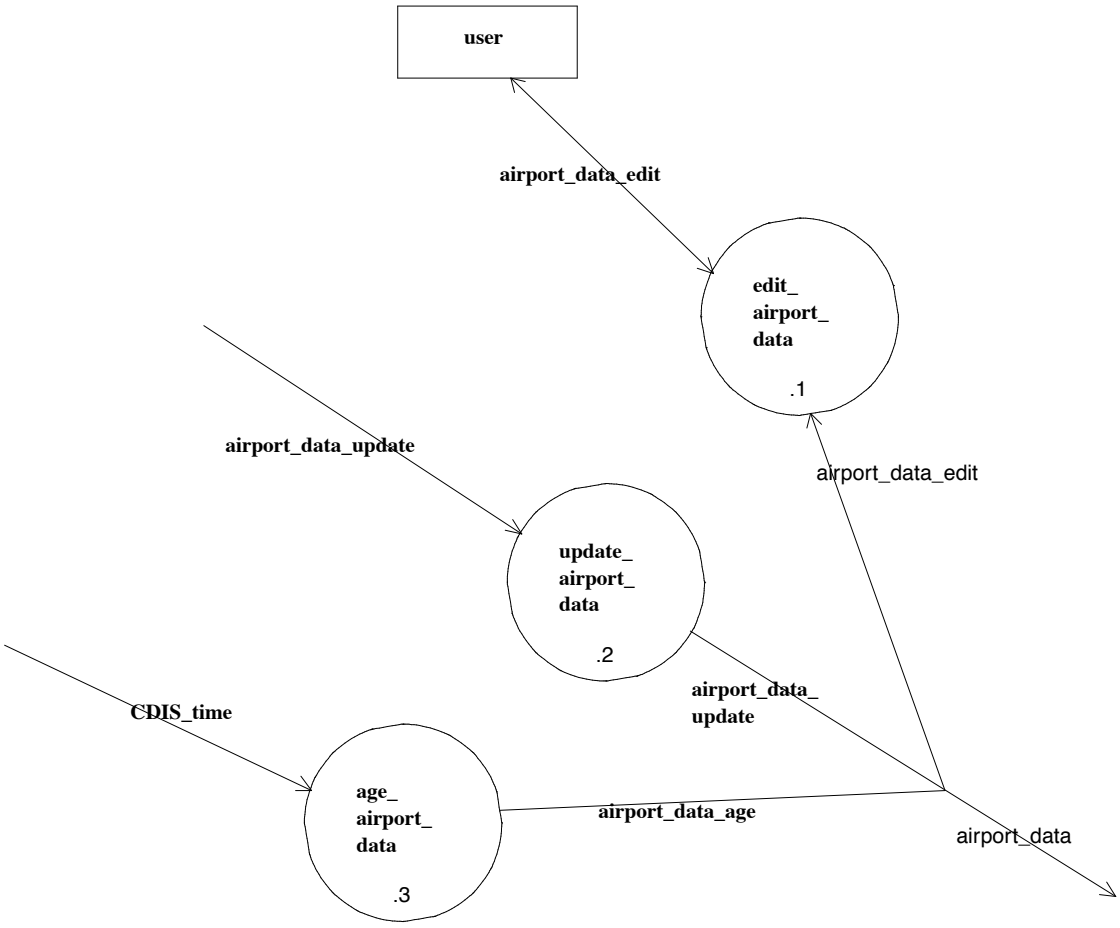
3.2 Manage airport data

Principles

- Airport operational information held by CDIS is updated either manually by data entry staff or in response to messages received from ADIS systems.
- Airport information will be marked to indicate whether it has been manually entered, is unavailable, or is out of date.
- A privileged user will be able to enter time parameters, used by the system to determine whether data is to be regarded as old or out of date.

Data flow diagram 3.2 with description



Process specifi cation:

3.2.1 **edit_airport_data**
User editing of airport data. Data so edited is displayed differently to distinguish it from live data.

input/ouputs

airport_data_edit
Commands from the user and corresponding changes to the database; plus database

displays to the user.

3.2.2 **update_airport_data**
Updates transient database following receipt of a message from an ADIS system.

inputs

airport_data_update
Updates on receipt of input from ADIS.

outputs

airport_data_update
Updates on receipt of input from ADIS.

3.2.3 **age_airport_data**
Airport data is aged; as time passes and no new airport data messages are receievd from ADIS, the state of the data moves from current/live to out-of-date, then to some extra-out-of-date status. Not relevant when the data has been manually input.

inputs

CDIS_time
To age the data.

outputs

airport_data_age
Causing the data to be labelled with the appropriate status indication.

3.3 Error & exception handling

CDIS shall offer a systematic treatment of error and exceptional conditions. This shall include timely, accurate recording of properly-identified error information. An interface to a separate, special purpose alarms system, **EMC**, shall be offered by CDIS.

3.4 System configuration/adaptation

The CDIS system must be adaptable in a number of respects, including at least the following areas:

- The facilities available at user positions, in terms of hardware and software.
- Various timing parameters, such as for ageing transient data, sending broadcasts on shutdown, removing broadcasts from the system, timeout parameters such as for flights landing and departing.
- Valid ranges for selected transient data.
- Transient data to be flagged on change, and roles required to acknowledge the change.

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4 PERFORMANCE AND SIZING REQUIREMENTS

4.1 Performance

The following are the performance requirements for CDIS.

For all the performance requirements, in 95% of cases they will fall within the required time.

4.1.1 System Start-Up

4.1.1.1

traceunit REQ.PERF.COLD_START

The time to cold start CDIS, when no more than thirty pages are out of date on the PS/2s, shall be no more than fi fteen minutes, measured from giving the start CDIS command to the point where all user interfaces are displayed and call attempts have been made to all ADIS systems.

4.1.2 Workstation User Interface

The following are the maximum delays. They include transmission delays within CDIS where applicable.

a.

traceunit REQ.PERF.CURSOR

Time from initiating a cursor movement to the movement being visible on the screen:
- no perceptible delay under peak loading.

b.

traceunit REQ.PERF.MENU

Time from initiating a menu selection to a visible indication of the selection being given:
- 100ms under peak loading

NOTE: 'Visible indication of a selection' is be any change in the display which indicates

that the operation has started, and not completion of the associated operation.

c.

traceunit REQ.PERF.DATA_ENTRY

Time from entry of data to its display on the screen at the entry position:

- 200ms under peak loading

d.

traceunit REQ.PERF.TEXT_DISPLAY

Time from completing the selection of a text page at a position to the display being complete at that position:

- 2 seconds

NOTE: This requirement is to be tested on a page agreed between the contractor and CAA.

e.

traceunit REQ.PERF.GRAPHICS_DISPLAY

Time from completing the selection of a graphics page at a position to the display being complete at that position:

- 2 seconds

NOTE: This requirement is to be tested on a page agreed between the contractor and CAA.

f.

traceunit REQ.PERF.UPDATE_DATA

Update of textual airport data following receipt of data from ADIS:

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- 2 seconds

g.

traceunit REQ.PERF.UPDATE_GRAPHIC

Update of graphical airport data following receipt of data from ADIS:

- 3 seconds

NOTE: This requirement is to be tested on a page agreed between the contractor and CAA.

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A APPENDIX: Glossary of Terms

ATIS	Airfield Terminal Identification Service
ADIS	Airport Display Information System
Alarm system	The system which monitors the health of CDIS hardware elements.
ASA	Approach Sequence Allocator
ASNo	Approach Sequence Number
ATC	Air Traffic Control
ATCA	(Same as ATSA)
ATCO	Air Traffic Control Officer
ATSA	Air Traffic Support Assistant
Bandboxing	Grouping several ATC responsibilities at one suite.
CAA	Civil Aviation Authority
CAP	Common Approach Point
CAPS	CDIS Administrational Processing Subsystem
CAPSIN	Civil Aviation Packet Switching Integrated Network
CASOR	Civil Airspace Operations Room
CCF	Central Control Function
CCPS	CDIS Central Processing Subsystem
CCTV	Closed Circuit Television System
CDIS	CCF Display and Information System
CERD	Computer Entry and Readout Device
CERDI	Computer Entry and Readout Device Interface
CLAN	CDIS Local Area Network
CQF	CDIS Query Form
COPS	CDIS Operational Processing Subsystem
CSIS	CCF Support Information System
CTS	Central Time Source (same as TIMEON)
CID	Computer Identifier (of a flight)
DM	Departure Message
EDD	Electronic Data Display
EDDUS	Electronic Data Display and Update System
E-R	Entity-Relationship
ETA	Estimated Time of Arrival
Fastkey	A PSD key bound to a predefined page, giving single key-stroke recall
FIN	Final (approach) director
FIR	Flight Information Region
GMC	Ground Movement Control
HCS	Host Computer System
ICD	Interface Control Document
ILS	Instrument Landing System
INT	Intermediate (approach) director
IRVR	Instrument Runway Visual Range
LATCC	London Air Traffic Control Centre
LTMA	London TMA
MAC	Major Airport Complex
EMC	Equipment Maintenance Control
MTBF	Mean Time Between Failures

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MTTR	Mean Time To Restoration
NAS	National Airspace System (same as HCS)
NATS	National Air Traffi c Services
NDB	Non-Directional Beacon
PSD	Page Selection Device
PSDI	Page Selection Device Interface
SADIE	Sequence Allocator and Director Interface Equipment
SCA	Speed Control Advice
SID	Standard Instrument Departure
SIRS	Support Information Retrieval System
TIMEON	same as CTS
TMA	Terminal Manoeuvering Area
TRQ	Timed Release Queue
TSD	Terminal Stack Delay
VDM	Vienna Development Method
VOR	VHF Omnidirectional Radio-beacon

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B APPENDIX: INDEX OF TRACEUNITS

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SECTION 6. REQUIREMENTS DOCUMENT FOR CASE STUDY 5: AMBIENT CAMPUS – THE LECTURE SCENARIO

6.1. Introduction

This case study captures several main characteristics of the ambient intelligence applications, which are to be built as open and dynamic pervasive systems involving people that carry handheld devices to help them in their daily activities.

The chief objectives of the Ambient Campus case study are to

- elucidate the specific fault tolerance and modelling techniques appropriate for the application domain
- validate the methodology developed in WP2, the basic kernel plug-ins from WP3 and the model checking plug-in supporting verification based on partial-order reductions
- document the experience in the forms of guidelines and fault tolerance templates.

The case study will be investigated as a series of scenarios. This section describes the requirements for the first scenario (i.e. the lecture scenario) in which we propose and evaluate initial development techniques, develop the first prototype, accumulate experience in dealing with fault tolerance and mobility during rigorous system development and gain first experience with the use of mobile computing devices and wireless networks.

In this scenario we deal with a number of faults. In our analysis of the environment and of the system, we have identified these faults as being typical for the *ambient intelligence* (AmI) systems of this type. Dealing with this representative set of faults in this scenario will allow us to generalise our experience and to produce fault tolerance and mobility templates and guides assisting the developers of the future AmI applications.

In this section, the term **users** denotes people actively participating in our scenario (i.e. teachers and students) and the term **agents** refers to software running on *personal digital assistants* (PDAs) or desktop computers. We will also differentiate between actions of users and agents. In the context of the agents, we refer to **services** that these agents and *Ambient Campus Environment* (ACE) provide to users. Users, in turn, are involved in **activity** when they are using agent services.

We assume that users' activities are defined before the the system is defined and developed (for example, teachers deliver lecture material, and students attend lectures, among others) although they do not include additional services provided by agents. Our goals are to define and implement agent services that assist the users in performing the activities defined in this section. One of the results of this work will be the development of software that implements the agents used in the scenario described in this section.

6.2. Requirements Taxonomy

The requirements are classified into several categories that represent the taxonomy.

1. **EN** – *Environment*: statements about the required properties of users, agents and ACE.

2. **FT** - *Fault tolerance*: the system should be able to tolerate a number of abnormal situations such as connectivity loss, failures of PDAs and desktop computers, violation of time constraints and fire alarms. These requirements define a set of related abnormal situations.

3. **ST** – *Agent state*: statements defining how the agents change their states depending on the role or activity they are performing at a particular time.

4. **SV** - *Service requirements and restrictions*: these requirements define the services provided by agents and ACE.

5. **QL** - *Service quality*: for some of the services provided by the agents, this section sets additional requirements related to the quality of service, such as performance and resource usage.

6. **SE** – *Security*: these requirements capture all the issues related to access permission, authorization and shared resource access.

7. **TT** – *Delays and timeouts* associated with various services or service quality requirements.

Some of the requirements are linked to other requirements. When this happens, a list pointers to the relevant requirements is given after the description of that requirement.

6.3. Scenario Environment

At the high-level view of the scenario we have users, locations and *ambient computing environment* (ACE).

EN. 1: The scenario is composed of users, locations and ambient computing environment (ACE)

The term "user" denotes a person actively participating in our scenario; this could be a teacher or a student.

EN. 2: A user is a teacher or a student

Location refers to a room on campus that has a hotspot which provides wireless connectivity. Connectivity areas may reach beyond the room or even cover several rooms. Connectivity areas may also overlap (see Figure 6.1).

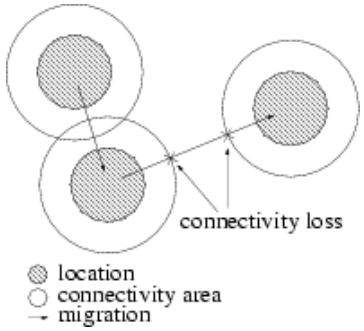

Figure 6.1: Location and connectivity area

EN. 3: Location is a room with a wireless connectivity provided by a hotspot

Each location also has a desktop computer, which is to be used by the teacher to join the scenario. This desktop computer (in conjunction with an overhead data projector – which will also be available in the room, but is not of interest in our scenario) will also be used by the teacher as a means to deliver the lecture materials such as slides, demos or videos.

EN. 4: Each location is equipped with a desktop computer which is to be used by the teacher

At any moment any user can be in at most one location.

EN. 5: At any moment any user can be in at most one location

ACE is composed of agents, hotspots that support wireless communication among agents, personal digital assistants (PDAs) and desktop computers.

EN. 6: ACE is composed of agents, hotspots, personal digital assistants (PDAs) and desktop computers

An "agent" is a piece of software that runs on PDAs or desktop computers, with a purpose to support lecturing activity.

EN. 7: An agent is a piece of software running on PDAs or desktop computer, supporting lecturing activity

The interactions among users (teacher and students) are done through agents. Each user will have an agent associated with them in a one-to-one relationship.

EN. 8: Each user has a unique agent representing them in the interactions within the scenario

ACE is intended to provide additional services for effective communication between teacher and students and among students during lectures. Each student user is given a PDA, through which he/she is involved into the scenario. PDAs may also be used to write and run small programs, for quiz taking and for collaboration between students.

EN. 9: Each student user has a PDA

Any agent can take one of the two roles: the teacher role or the student role.

EN. 10: An agent can take a role of a teacher or a student

The student agent interacts through a PDA while the teacher agent interacts through a desktop computer.

EN. 11: Student agent interacts through a PDA (see EN. 9)

EN. 12: Teacher agent interacts through a desktop computer (see EN. 4)

EN. 11 and EN. 12 above allow a teacher user (i.e. a person whose job is to teach) to act as a student in some lecture by joining the scenario using a PDA; or a student user to give a lecture in some special cases by using the desktop computer available in that lecture room.

To simplify the model, we only consider activities performed by the users through their agents during lectures. However, we want to explicitly introduce the states that an agent can be in. There are four top level states for an agent: *lecture*, *free*, *migrating, outside* and *emergency*.

ST. 1: The agents' top-level states are *lecture*, *free*, *migrating*, *outside* and *emergency*

For better scenario structuring, we allow states to have sub-states. A tree-structure is used, where the sub-states are represented as branches of the parent or container state.

ST. 2: Top-level states may have sub-states

The sub-states serve as a logical boundary grouping several independent services. On entering a sub-state, agent preserves access to all of the services of the containing state and acquires a new set of services associated with this sub-state.

ST. 3: On entering a sub-state, an agent preserves the services associated with the containing state, and acquires a new set of services

When an agent enters a sub-state, it is still considered to be in all of the parent states. One of the top-level states, as given in ST. 1, is always associated with each agent.

ST. 4: An agent is always associated with one of the top-level states (see ST. 1)

Lecture state corresponds to a lecture-type joint activity involving students and teacher. This is the most complex state in the scenario and it contains several sub-states. We will discuss the lecture state in section 6.4 whereas the rest of the states will be discussed later in section 6.5.

6.4. Lecture State

Here we mostly focus on agent-related issues of in-lecture actions. ACE is intended to assist in delivering a lecture and we will determine activities that can be most successfully supported by ACE. We break the lecture activity into small functional blocks that are either lecture sub-states or service requirements. These blocks may be dynamically composed to form a unique lecture activity. The finer the block is, the more detailed and accurate lecture composition could be achieved. To start with, a lecture involves a teacher and several students located in the same location.

EN. 13: A lecture involves a teacher and several students in the same location

It is not allowed to have more than one lecture happening in the same location at the same time. It is possible to have no lecture happening in a given location at a given time.

EN. 14: At any moment, only up to one lecture can be given in one location

Only teacher can deliver lectures.

EN. 15: Only teacher can deliver lectures

A user acts as a teacher by logging in to the desktop computer available in the lecture room. This user's agent then assumes the teacher role.

EN. 16: When a user logs in to the desktop computer in the lecture room, its agent assumes the role of a teacher (see EN. 4 and EN. 12)

A user coming to a lecture room with a PDA will assume the student role.

> EN. 17: Agents of the users joining the lecture through their PDAs will assume the role of a student (see EN. 9 and EN. 11)

It is not allowed for a user to participate in a given lecture with more than one role. We also prevent a user from participating in several lectures at the same time while in one location when there is an overlap of connectivity areas – see Figure 6.1.

> EN. 18: Each user's agent can only take one role per location

Once an agent is involved in a lecture and takes a particular role, it cannot change its role from student to teacher or vice versa during that lecture.

> EN. 19: Once an agent assumes a role in a lecture, it cannot change its role throughout the duration of that lecture

The teacher should be able to control the use of PDAs and wireless networks in that location.

> EN. 20: Teacher has full control of the PDAs and wireless networks at the location he/she is currently teaching

Each lecture is associated with a particular module. This is to allow scheduling and to make distinction among lectures.

> EN. 21: Each lecture is associated with a module

A module is equivalent to a course or class as defined by the university or a school within the university. It represents a basic unit of study within a degree programme. We will not discuss it further in this section.

Lecture state has two sub-states: individual state and group state.

> ST. 5: Lecture state has two sub-states: individual state and group state

Individual state is associated with the situation where the teacher gives individual task to the students (see section 6.4.4), whereas the group state relates to the group task activities (see 6.4.5 and 6.4.3). Figure 6.2 shows the states involved in a lecture.

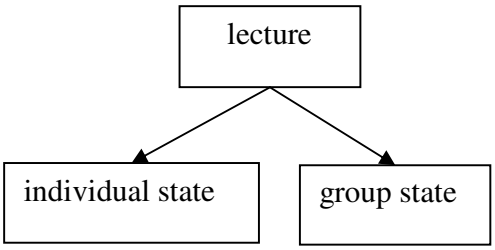

Figure 6.2: Lecture state and its sub-states

We will now discuss the activities (and their related services) that are performed by teacher and students (through their agents) during a lecture.

6.4.1. Lecture initiation

For a lecture to begin there should be a teacher and several students in the same location. Not all of the students may have a PDA but there should be some minimal number of students with working PDAs, otherwise ACE support for the lecture will be automatically halted. There may be other start preconditions, including specific preconditions for teacher and lecture module, but for now we will just keep it simple.

> SV. 1: For ACE-supported lecture to begin, there should be one teacher agent and several student agents in the same location

A lecture begins with the teacher – through his/her agent – taking a register of all the students present in the lecture room.

> SV. 2: Lecture begins with the teacher agent requesting registration of the students present in the lecture room

Students' PDAs automatically submit student registration data (such as student's login id, name and course or module taken) upon the registration request raised by the teacher agent in SV. 2.

> SV. 3: Upon registration request (see SV. 2), student agents submit their registration data to the teacher agent

The teacher agent must assist the teacher in validating students' registration data. Examples of bogus data include copied student identification or unauthorized use of a borrowed PDA.

> FT. 1: Student agent may send invalid, incomplete or bogus registration data (see SV. 3)

The registration process should take finite time, as specified by the timeout TT. 1 (see section 6.8). The timeout delay will be found out experimentally so that use of ACE during registration is comfortable for both teacher and students.

> QL. 1: Registration phase should be completed within the timeout TT. 1 (see SV. 2)

Some students for some reasons which we ignore in this scenario may be disallowed to attend a particular module. The teacher then checks access rights for the students and rejects those who cannot attend the lecture.

> SV. 4: Teacher agent checks access rights for each student agent

An obvious source of failures we have to take into account here is insufficient or lack of access rights for some of the students.

> FT. 2: Some students may not have proper access rights to attend the lecture (see SV. 4)

All we have to do in this situation is to make sure that such student cannot participate in the ACE-supported lecture activities, although they might be allowed to sit through the lecture.

> SE. 1: Students without proper access rights cannot participate in ACE-supported lecture (see FT. 2)

Teacher agent registers all students with proper access rights.

> SE. 2: Only students with proper access rights are registered to the ACE-supported lecture (see FT. 2 and SE. 1)

When all the participating students are known, the lecture environment is configured as specified by the teacher for the duration of the lecture.

> SV. 5: Teacher agent configures lecture environment for all registered student agents for the duration of the lecture

There should be a feature that allows remote configuration and software update to the registered student agents to be performed by the teacher. This might include enabling/disabling of certain ACE services, uploading new agent software on student PDAs or restricting access to some services on student PDAs.

SV. 6: There should be a feature to allow teacher agent to perform remote configuration and software update on the registered student agents (see SV. 5)

To enable closer and more synchronous cooperation with the students, the teacher issues a key which allows the students to trigger services in the teacher agent. This enables addressed and private communication between the students and the teacher. Only registered students are allowed to communicate with the teacher through ACE support (see SE. 1)

SV. 7: Teacher agent distributes lecture key to the registered student agents

SV. 8: Registered student agents wait for the lecture key to come from the teacher agent

Key distribution must not take too long and should finish within some timeout TT. 2. Unlike TT. 1, TT. 2 timeout should be quite small as this stage does not require any attention from the users.

QL. 2: Lecture key distribution should finish within the timeout TT. 2 (see SV. 7 and SV. 8)

It is a major security problem if the key is received and used by some unauthorized student or a malicious agent. We must ensure that only eligible students can receive the lecture key.

SE. 3: Lecture key should only be received by the registered student agents (see SV. 4, SE. 2, SV. 7)

A student without appropriate key cannot enter the ACE-supported part of a lecture. This is another security measure on top of SE. 1.

SE. 4: Students without a lecture key cannot participate in ACE-based lecture activities (see SV. 7, SE. 3)

We must account for the case when not all the students get the key within the timeout TT. 2.

FT. 3: Some registered students might not receive the key during the timeout TT. 2 (see SV. 7, QL. 2)

Teacher agent must provide some assistance to the teacher in this situation.

Some students might turn up at the lecture late (i.e. after the registration process is completed and lecture keys have been distributed).

FT. 4: Some students might turn up at the lecture late (i.e. after the registration process is completed and lecture keys have been distributed)

In this case, they might attempt to join the ACE-supported lecture by sending their registration data to the teacher agent.

SV. 9: Late students might attempt to register to the lecture (see FT. 4)

Teacher agent must be able to detect registration requests from late students and allow the teacher to decide whether to let them join or not (for example, they might be too late to join a group discussion).

SV. 10: Teacher agent must be able to handle registration request from late students (see FT. 4 and SV. 9)

If the teacher allows the late students to join, teacher agent will send the lecture key to the student agents of these late students.

SV. 11: Teacher agent might issue lecture key to the agent of students arriving late to the lecture (see FT. 4)

6.4.2. Material dissemination

Teacher distributes the information related to the lecture, such as lecture notes or reading list, directly onto student PDAs. Students can read this information during the lecture and save it in their private storage space for later use.

SV. 12: Teacher distributes lecture material

SV. 13: Students wait for the lecture material and save it on their PDA

Distribution of lecture material can happen several times during one lecture. However, students must be prepared to respond to this action, which means that they might need to stop or suspend their current activity. This may be initiated either by ACE tools or by the teacher (verbally) asking the students to put their PDAs in a certain operation mode.

SV. 14: Teacher notifies the students to get prepared to receive the lecture material

When the students are ready, the material can be sent out. Teacher agent sends the lecture material and then waits for the acknowledgements from all the students through their agents.

SV. 15: Teacher agent sends out lecture material to student agents

Students, through their agents save the lecture material on their PDAs.

SV. 16: Student agents receive the lecture material and save it locally on student PDAs

Each student agent sends an acknowledgement back to the teacher agent that they have received the lecture material.

SV. 17: Student agents send an acknowledgement to the teacher agent on the receipt of the lecture material

The acknowledgements should arrive within the predefined timeout TT. 3 from the time the teacher agent sent the lecture material. Since this procedure does not include any actions from users the timeout should be quite small.

QL. 3: Lecture material receipt should be acknowledged by all the student agents within the timeout TT. 3

It is possible that the lecture material or the acknowledgement receipt of lecture material do not arrive within timeout TT. 3.

FT. 5: Lecture material may not arrive within the timeout TT. 3

FT. 6: Lecture material receipt acknowledgement may not arrive within the timeout TT. 3

As a consequence, the teacher agent might not receive all lecture material receipt acknowledgements from all student agents within timeout TT. 3.

FT. 7: Teacher agent does not receive lecture material receipt acknowledgements from all student agents within timeout TT. 3 (see FT. 5, FT. 6)

If FT. 7 happens then something must have gone wrong and the users with the help from their agents must handle the situation. The easiest way to handle this is by having the teacher agent to re-send the lecture material.

QL. 4: In case of failure (FT. 7), service SV. 12 may be restarted

6.4.3. Organization into groups

Students may be organized into groups to work on some task or for a group discussion.

SV. 18: Teacher organises students into groups

Student agents must be put into a certain mode to accept group organization request from the teacher agent. Once again, this can be achieved either by ACE or oral communication between the teacher and the students.

SV. 19: Teacher agent sends group organisation request to all student agents

Upon this group organization request, the students must stop their current activity and set their agents to get into the group state. This might require some state serialization or data backup for any interrupted activities to be resumed later.

SV. 20: Having received group organization request (see SV. 19), students must cease any other activity and prepare to enter the group state

To differentiate between the groups, the teacher must assign names to them. Each student receives the name of the group to which he/she belongs to.

SV. 21: Teacher agent sends to each student agent the name of the group that they belong to

Each student agent sends a message back to the teacher agent to acknowledge that the group name is received.

SV. 22: Each student agent sends an acknowledgement on the receipt of their group name to the teacher agent

The teacher agent must receive the acknowledgements from all student agents that they have received their group name within timeout TT. 4.

QL. 5: Teacher agent must receive the acknowledgements from all student agents that they have received their group name within timeout TT. 4

We must take into account the situation where some student agents are unable to enter their allocated group because they did not receive the name of their group or something was wrong with their PDA.

> FT. 8: Teacher agent might not receive acknowledgement of group name receipt from all student agents within timeout TT. 4

If the teacher agent does not receive group name acknowledgement receipts from all student agents within the timeout TT. 4 then some recovery actions must be taken by the teacher agent. The teacher might decide to either drop ACE support for group organisation during this lecture or organise students in a different way ignoring those problematic agents.

With a group name, student agents gain ability to send messages to other participants of the same group.

> SV. 23: Group name gives the ability to a student agent communicate with other students within the same group

On the other hand, when in a group, a student cannot communicate with other students outside of his/her group.

> SV. 24: Student agents cannot communicate with other student agents outside the current group they belong to

Student agent can always communicate with the teacher agent during the lecture, regardless of the group organisation.

> SV. 25: Student agents can always communicate with the teacher agent during the lecture

At any given time during a lecture, each student agent can be only in one group.

> SE. 5: Each student agent belongs to only one group at any given time during a lecture

We must ensure that each student is really participating in the group to which they are assigned to. There must be no way for the students to break this rule.

> SE. 6: Teacher makes sure that each student is in the right group

Group is a sub-state of the lecture state. If the whole lecture is abandoned then all the nested groups and other nested states are automatically destroyed.

ST. 6: Group is a sub-state available to student agents during a lecture

If no group is formed, students may be allowed to freely communicate with each other. At the beginning of each lecture, all student agents are placed in the same group.

QL. 6: Lecture starts with all the student agents placed in the same group

6.4.4. Individual task

Teacher may give individual task and collect the answers (using the ACE support) during the lecture or sometime later. It is up to the teacher to determine when the students must present the answer.

SV. 26: Teacher may give individual task

SV. 27: Students must be able to accept an individual task given by the teacher

Before receiving the task, students must stop any other activities and prepare to receive the task.

SV. 28: Students prepare to take the individual task given by the teacher

Teacher, through their agent, can send the individual task material to the students anytime during the lecture.

SV. 29: Teacher agent sends the individual task material to the student agents

Students, through their agents, must then accept the task material and save it locally on their PDA.

SV. 30: Student agents receive the individual task material and save it locally on their PDA

Students must acknowledge that the individual task material has actually arrived.

QL. 7: The individual task material receipt must be acknowledged by each student within the timeout TT. 5

Teacher agent should provide some automatic or semi-automatic recovery in a case where some students did not acknowledge the material receipt.

FT. 9: Not all student agents acknowledge the receipt of the individual task material within timeout TT. 5 (see QL. 7)

In the case of FT. 9, recovery is required only for the students which have not received the material.

QL. 8: In case of failure FT. 9, service SV. 29 may be repeated

Each student must eventually send the answer to the task, although they might not be required to do this during the lecture.

SV. 31: Each student must eventually send the answer to the individual task

QL. 9: Student's answer to the individual task might be sent after the end of the lecture (see SV. 31)

After some time, maybe after the lecture ends, the teacher receives the answers and checks their correctness.

SV. 32: Teacher checks all of the submitted answers for the individual task

There may be a case when student mistakenly sends an answer to a wrong teacher. Such situation must be sorted out automatically by the teacher agent and must not take any of the teacher's time.

FT. 10: The individual task answer could be sent by unauthorized student

FT. 11: The individual task answer could be sent to a wrong teacher

We require that any recovery action should hide unauthorized messages from teacher agent user.

SE. 7: Teacher agent must silently ignore individual task answers from unauthorized student agents (see FT. 10, FT. 11)

Since answers may be used by teachers to assess student's performance, special attention should be paid to the detection of answers with faked credentials.

SE. 8: There must be no way for students to use fake credentials when sending the answer to the individual task

6.4.5. Group task

Teacher may also give a group task to the students. Students are arranged into groups and students in each group work together to provide an answer to the task.

SV. 33: Teacher may give group task (see SV. 18)

SV. 34: Students must be able to accept a group task given by the teacher

As in the case with individual task, we must ensure that each student in the group is ready to take the task.

SV. 35: Students in each group prepare to take a group task given by the teacher

Teacher agent sends the group task material to all groups.

SV. 36: Teacher agent sends the group task material to student agents in each group

Student agents then accept the group task material and save it locally on their PDA.

SV. 37: Student agents in each group receive the group task material and save it locally on their PDA

Each group must acknowledge the receipt of task material.

QL. 10: The group task material receipt must be acknowledged by each group within the timeout TT. 6

Teacher agent must handle the situation when one or more groups do not send an acknowledgement.

> FT. 12: Not all the groups acknowledge the receipt of the group task material within timeout TT. 6 (see QL. 10)

In the case of FT. 12 failure, the teacher might decide to resend the group task material to some or all of the groups.

> QL. 11: In case of failure FT. 10, service SV. 36 may be repeated

Each group must present the group answer to the teacher sometime during the lecture.

> QL. 12: The answer or indication of inability to answer the group task must be received by the teacher before the lecture ends

Teacher collects the answers from all the groups and checks their correctness.

> SV. 38: Teacher checks all of the submitted answers for the group task

It is possible that a group sends several answers for the same task. Teacher agent must detect such situation and resolve this automatically or assist the teacher on this matter.

> FT. 13: There may be more than one answer submitted by a group

Just like in the case with individual tasks, correct credential for the group answers is an important security issue.

> SE. 9: There must be no way for groups to use fake group credentials when sending the answer to the group task

6.4.6. Questions from students

There is one kind of activity that is initiated by the students. Students, through their agents, may ask questions to the teacher any time during the lecture (even during an individual or a group task). This is the main communication channel from students to the teacher.

SV. 39: Students may directly ask questions to the teacher through their agents

Teacher agent must immediately detect any questions from students.

SV. 40: Teacher agent must be able to detect questions raised by the students

Teacher may answer immediately or later during the lecture or after the lecture or never at all. The answer may be private or public and can be given through ACE tools or in natural language or both.

SV. 41: Teacher may answer the questions raised by the students

SV. 42: Teacher's answer could be delivered through ACE or by traditional means (orally)

Questions may arrive simultaneously from several students, so teacher agent should sort and store these questions to be viewed and answered later by the teacher.

QL. 13: Teacher agent should be capable of handling multiple questions at the same time

Teacher agent must ignore any questions originating from students not participating in the current lecture.

SE. 10: Questions from students not participating in the lecture must be ignored by the teacher agent

6.4.7. Lecture ending

Lecture ends when certain conditions are broken. If most of the students or the teacher has left the lecture then we assume that there is no need to provide agent-level support for lecture activity.

SV. 43: Lecture ends when there are less than N students or there is no teacher in the location

When lecture ends, all users might still stay in the same location but without any joint activity. They can either migrate to other location or organize a new lecture in the same location.

ST. 7: When a lecture ends or a user leaves the lecture location, the user's agent's state is changed to free (see ST. 18)

ST. 7 above mentions "free" state. The meaning of this state is described in section 6.5.1.

6.5. Other states

Lecture state is the largest part of the scenario. To simplify its description we decided to focus only on the lecture part and present a simplified view on the scenario for the readers. However it is impossible to build a complete system with an obscure and undefined "not-in-lecture" state.

Not-in-lecture is an abstract state solely used to enable transition to/from the lecture part of the scenario from/to the rest. As shown in the Figure 6.3 below, not-in-lecture state corresponds to two states: *free* and *migration*.

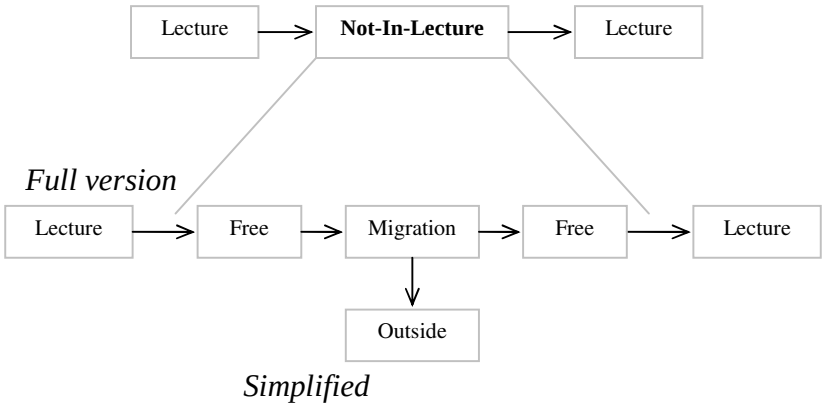

Figure 6.3: New look at state transition between lectures

"Free" state is an intermediate state which is used to give agents a choice of whether to participate in a lecture or migrate somewhere else or stay in the current location. An agent can stay in a free state for as long as it wants.

"Migration" state is a situation where an agent is in the process of moving from one location to another. It was introduced to explicitly deal with physical migration problems present in mobile software. Migration process takes some time, during which many events and failures may occur and we want to explicitly introduce migration state, as connectivity-related failures are important to us.

There are two other top level states: outside and emergency (see ST. 1)

"Outside" state represents the state of those agents currently not participating in the scenario but

can join the scenario. Agents also leave the scenario by changing their state to outside.

"Emergency" state is used to coordinately handle local or global emergency situations, such as fire alarm or electricity loss. This state is somewhat a special case here, where it is used to coordinate agents and users during recovery actions that require location-wide or even global recovery actions. There may be a transition to this state from any other states except outside state.

The full diagram of the states present in the scenario is shown on the Figure 6.4.

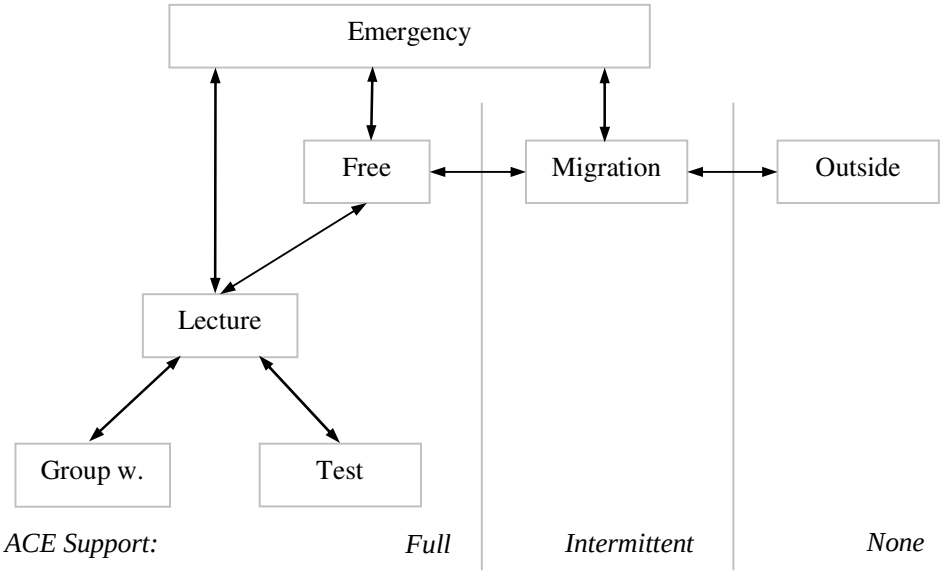

Figure 6.4: Full diagram of the scenario states

Failures may lead to transition to emergency state from lecture, free and migration states. For the sub-states of lecture state we require the nested activities to be finished prior to transition to emergency state. Effectively it is means usage of state-specific recovery procedures for the sub-states.

States are also classified by the quality of ACE support. To simplify the scenario we do not deal we disconnection and other connectivity problems in free and lecture states. The focus on that is made in migration state, where we expect agents to experience repeated disconnections. Agents in outside state are not part of the scenario and even if they in a hotspot coverage area, there is no ACE support for them.

6.5.1. Free State

A user's agent is in a "free" state when the user is located in an ACE supported location but is not participating in a lecture. Under normal circumstances, a user's agent that is currently in a "free" state can only change its state to either migration or lecture.

ST. 8: User's agent in free activity state can migrate to a different location

ST. 9: User's agent in free activity state can register in a lecture happening in the location where the user is currently located

When global emergency state is activated, the state of every user's agent in a given location must also be changed to emergency state.

ST. 10: User's agent's free activity state is changed to emergency state when emergency state is globally activated

6.5.2. Migration State

Migration state captures details of the physical migration of the users, and along with that, the migration of the users' agents in term of the connectivity area. This stage may include network disconnections and partial or total loss of ACE support.

FT. 14: Migration activity must tolerate wireless network disconnection and loss of ACE support

Network connection must be automatically reestablished when an agent enters into area covered by a wireless hotspot.

QL. 14: Agent must reestablish the network connection as soon as it enters wireless hotspot connectivity area

Agent must be able to continue its operation despite some operations may be interrupted by disconnection.

FT. 15: Any operations in migration stage must be able to tolerate permanent and temporary disconnections

When an agent enters an area of another hotspot or reestablishes connectivity with the original location, the agent's state is changed to the "free" state.

ST. 11: Migration state changes to free state when the migrating agent appears in one of the scenario locations

An agent in migration state can change its state to outside at any moment, independent of the ACE or connectivity state. When agent changes its state to outside, it effectively leaves the scenario.

> ST. 12: Agents currently in migration state may change their state to outside

If a global emergency is activated, all currently migrating agents must be switched into emergency state. However it is impossible to do it if there is no ACE support. In this case, emergency state for the agent is triggered later when the user with this agent comes to an area with ACE support. If ACE support is reestablished after the emergency situation is resolved then no emergency state transition is required for the particular agent.

> ST. 13: Agents in migration state and with active ACE support will change their state to emergency when a global emergency is activated

6.5.3. Outside State

Outside state is a way to represent the state of those agents whose users are currently not participating in the scenario. We are not concerned with their particular sub-states or activities and do not provide any services to them.

> ST. 14: New agents appear and disappear in the scenario by changing their state from/to outside state

We are not concerned with the problem of how new agents are selected and when they should appear. This is left to the agents' users and not specified in the scenario.

6.5.4. Emergency State and Failures

In defining the fault tolerance requirements, we rely on the general framework for dependability engineering from [6.1]. This framework defines the process of development of these requirements in terms of identifying the fault assumptions, i.e. the events that might have unacceptable consequences on the system and its environment if not tolerated. In the Ambient Campus case study, these events come from both the system itself and its environment. Where appropriate, we augment the description of the failure assumption with the description of the required degraded operation mode.

6.5.4.1. ACE Support

Due to the possibility of failures in ACE during a lecture, there may be cases where ACE support for some or all of the students or for the teacher is not available. We consider this as if the student or the teacher leaves the lecture. In the case where a considerable number of students

leave or if the teacher leaves, ACE support for the rest of the participants is stopped. However, the lecture may continue in the traditional way. We assume that only one fault can happen at a time.

6.5.4.2. Failures

There could be cases where one or more student experiences PDA failure or their ACE support is temporary halted. There should be some recovery procedure to allow PDAs to be quickly configured so that they are ready to be used in ACE.

FT. 16: Student's PDA may fail on some operations

If recovery for the student agent participating in the lecture activity succeeds then ACE support for that agent will be restored.

QL. 15: Student's agent should recover, if possible, from a PDA failure during the lecture (see FT. 16)

QL. 16: Upon successful recovery, ACE support for the failed PDA can be restored (see FT. 16, QL. 15)

Students with a completely failed PDA should try to continue following the lecture without ACE support. In some cases, this event may drop ACE support for the whole lecture.

FT. 17: Student's PDA may completely stop working

Note that in some cases, FT. 16 and FT. 17 may result in the whole ACE support for the lecture to be stopped (see requirement SV. 43).

Fire alarm can be toggled automatically in all the locations of the scenario. We assume that ACE support can be operational for long enough to be used to help the students and the teacher to leave the building.

FT. 18: Fire alarm may be activated in all the scenario locations at the same time

In the case of such an event, all users within the scenario must leave the building. Recovery action for fire alarms attempts to change the state of all the agents in the scenario to emergency. Note that for lecture sub-states we do not allow direct transition to any emergency state, thus lecture sub-states are first aborted (with their own recovery procedure) and only then the agents are put into emergency state.

ST. 15: In the case of fire alarm, state of all the agents is changed to emergency (see FT. 18)

This state transition is referred-to in this section as a global emergency event.

PDAs should be used to guide users to the nearest fire exits. Since we do not expect the use of GPS or any other kind of navigation system, guidance provided is basically a map that shows nearest fire exits, based on the user's current location.

QL. 17: In case of fire, PDAs should guide users to the nearest fire exits (see FT. 18)

If fire alarm is de-activated, users can return to their interrupted activities. This means that they will return to the state from which the transition to emergency state was made.

ST. 16: If fire alarm is de-activated, the emergency state is changed to the most recent interrupted state (see FT. 18)

In the case of electricity failure, there is no wireless network. However PDAs with their independent power source may continue to operate.

FT. 19: Electricity failure may affect any location

Individual PDAs must backup their state so that the interrupted activity can be resumed later.

QL. 18: In case of electricity failure in the location, student agents must backup their state (see FT. 19)

When there is no wireless network there is effectively no location defined. This means that the agents must switch to migration state and either look for other locations in the scenario or leave the scenario altogether.

ST. 17: In case of electricity failure in the location, agents switch to migration state

If most of the agents, including the teacher agent, recovered then the lecture can be continued with ACE support.

QL. 19: If a minimal required number of students have recovered from FT. 19 then ACE support for the lecture can be reestablished

Generally this failure cannot be handled automatically by the agents and some assistance from the users is required.

6.6. Summary of the states

Now we can outline possible state transitions in the scenario. Only major states are included and transition for the lecture sub-states are discusses in lecture state section.

ST. 18: The following top-level states transitions are allowed:

	lecture	free	migration	outside	emergency
lecture		ST. 7	ST. 17		ST. 15
free	ST. 9		ST. 8		ST. 10, ST. 15
migration		ST. 11		ST. 14	ST. 13, ST. 15
outside			ST. 14		
emergency	ST. 16				

Requirement names given in the boxes provide additional explanation on the particular state change. The first column is for the initial states and the rows are for the destination. Blank boxes correspond to prohibited state changes or those state changes that are beyond our interest. Referenced requirements provide additional explanations of the transition.

6.7. Dynamicity and reconfigurability

To capture some dynamic aspects, the case study is modelled as an open system where the number of students and teachers can change dynamically. This is possible when each agent is somehow compatible with other agents. Agents in outside state do not have an ACE support, cannot participate in any activities and cannot be addressed by the members of the scenario.

EN. 22: ACE is disabled for agents in outside state

However, when an agent changes its state from outside to migration and appears in one of the scenario locations this is considered as appearance of a new participant in the scenario. Agents can temporary leave the scenario and later return back (see ST. 14).

Any agent that implements the functionality required by the scenario can join the scenario as a new participant. Also there must be a way to inspect agent capabilities to ensure that the agent/user pair can take part in the scenario and with the properly assigned role.

EN. 23: All agents in outside state have required functionality to participate in the scenario

For any agent with currently active ACE support it is possible to identify its physical location. It

is assumed that a user is always in the same location as his/her agent.

> EN. 24: Location is known for any agent with currently active ACE support

When a user is migrating and is not connected to any hotspot, we cannot associate them with any of the locations.

> ST. 19: User location is undefined during the migration stage when there is no ACE support

We cannot determine the routes for migrating users and they can finally show up in any location or leave the scenario. This is not a restriction since migration corresponds to users walking with their PDAs across campus and we cannot control their behavior.

> EN. 25: Users migration behaviour is non-detereministic

All locations have the same functionality. For simplicity we assume that any location can support any lecture type and users have no preference for any particular location.

> EN. 26: All the locations have the same functionality

However the number of locations is not fixed. We might introduce new locations in the scenario.

> EN. 27: New locations might be added to the scenario

Certain locations may be removed from the scenario, for example we might decide to drop ACE support in a particular lecture room.

> EN. 28: Existing locations might be removed from the scenario

6.8. Timeouts

This is the list of timeouts used in the scenario, they are all part of lecture state description. See the referenced requirements for further explanations of the timeouts.

> TT. 1: Lecture registration timeout, counting from SV. 2 (see QL. 1)

> TT. 2: Lecture key distribution timeout, counting from SV. 7 (see QL. 2)

TT. 3: Lecture material distribution timeout, counting from SV. 15 (see QL. 3)

TT. 4: Group name organisation timeout, counting from notification SV. 21 (see QL. 5)

TT. 5: Individual task distribution timeout, counting from SV. 29 (see QL. 7)

TT. 6: Group task distribution timeout, counting from SV. 36 (see QL. 10)

6.9. Acknowledgements

We would like to thank Jean-Raymond Abrial and Stéphane Lo Presti for their feedback.

6.10. References

[6.1] M. Kaaniche, J.-C. Laprie, J.-P. Blanquart. A framework for dependable engineering of critical systems. Safety Science 40, pp. 731-752, 2002