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A Method for Predicting Human Error in ATM (HERA-PREDICT)

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Abstract

This report has been developed among a series dealing with how human errors in Air Traffic Management (ATM) can be analysed and evaluated to improve safety and efficiency in European ATM operations. The purpose of this work is to develop an approach and methodology to predict human errors in the Air Traffic Control (ATC) environment.

This report includes the review of other predictive methods used in similar working environments and proposes a methodology to be used within the ATM operational situation. Finally it demonstrates the use of the proposed method to verify human error trends in the introduction of new technology in support of an existing task activity: Flight Progress Strips (FPS).

Keywords

Flight Progress Strips (FPS)	Functional Task Analysis (FTA)
HERA-JANUS Taxonomies	Human Error
Human Error Probability	Human Reliability Assessment (HRA)
Prediction	Prospective Assessment
Retrospective Analysis	Risk

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0.2	15.12.2001		Draft 1 (inclusion of practical application)	All
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1.0	05.03.2004	040201-02	Released Issue (agreed on 28-29.01.2004) (final configuration and editorial adjustments)	All

CONTENTS

EXECUTIVE SUMMARY

The general objective of the Human Error in ATM (HERA) Project is to investigate several specific areas associated with the prediction, detection and management of human error in Air Traffic Management (ATM), and to develop methods for the implementation of the results of these concepts at various levels of air traffic safety management within Europe.

Phase 1 of the HERA Project produced a detailed methodology and technique for analysing and learning from error-related incidents in ATM (see EATMP, 2002a, 2002b, 2003a, 2003b).

The objective of Phase 2 is to explore more intensively the potential operational applications of this error analysis technique, in relation to four specific safety-related areas:

- to develop an approach using the HERA-JANUS Technique to investigate how human error can be detected and managed within a real-time simulated ATC environment (HERA-OBSERVE) (see EATMP, 2002c, 2002d);

- to investigate the potential of the HERA-JANUS classification as a prospective tool within ATM (HERA-PREDICT) (covered by this report);

- to develop an approach using the HERA-JANUS classification tool for safety management within ATM (HERA-SMART) (see EATMP, 2003c);

- to develop teaching materials on the HERA-JANUS Technique for incident investigators and safety managers within several ECAC States (see EATMP, 2003d).

This report deals with the second of these four objectives: the investigation of the potential of the HERA-JANUS classification as a prospective tool within ATM – HERA-PREDICT. It presents the results of this study in two parts:

- firstly, the development of methodology based on the HERA-JANUS Technique, for predicting ATC errors and related performance;

- secondly, the validation of this method with a traditional and emerging technology associated with the ATM environment – Flight Progress Strips (FPS).

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1. INTRODUCTION

1.1 The HERA Project

Phase 1 of the Human Error in ATM (HERA) Project sought to review theories of human error and formulate a practical approach for analysing these errors within the ATM environment. This work arose as a result of increasing automation and the importance of error recovery and error reduction in ATM as the future traffic increases are predicted and as air space structures are re-aligned to produce maximum traffic flow. The resultant work in this first phase established the rationale for a conceptual framework for this initiative. This conceptual framework outlined a model of human performance and the types of taxonomies that would be required to classify errors and contextual factors relating to ATM incidents. This technique was then used in various validation exercises to establish its robustness, efficacy and usability (see EATMP, 2002a, 2002b, 2003a, 2003b).

Reliability and variations in human performance are an important element in the understanding of aviation safety and in analysis and design of air traffic management systems. The first phase of the project established a framework for understanding human errors in air traffic management operations and has provided a basis for better categorising air traffic management incident data. Statistics and trends obtained from applying these concepts have provided a basis for the application to a range of ATM activities, such as incident analysis and to a lesser extent the prediction of human performance with new ATM tools. However, the dearth of similar work indicated that there was a need to extend this activity into another dimension, that of prediction, detection and recovery of human error within the ATM system.

The general objectives of the second phase of the project, HERA 2, are to investigate several specific areas associated with the prediction, detection, and management of human error in air traffic management and to develop methods for the implementation of these concepts at various levels of the ATM system; such as safety training, safety management, incident investigation and the application of human error vulnerability within the system.

The specific objectives of HERA 2 are therefore the following:

- to develop an approach using the HERA-JANUS Technique to investigate how human error can be detected and managed within a real-time simulated ATC environment (HERA-OBSERVE) (see EATMP, 2002c, 2002d);

- to investigate the potential of the HERA-JANUS classification as a prospective tool within ATM (HERA-PREDICT) (covered by this report);

- to develop an approach using the HERA-JANUS classification Technique for safety management within ATM (HERA-SMART) (see EATMP, 2003c);

- to develop an approach, using the HERA-JANUS classification, for the training of incident investigators which incorporates an understanding of human factors and system safety aspects within the investigation process (see EATMP, 2003d).

1.2 Overall Work Plan and Focus of this Report

The overall work plan for this part of the HERA Project, HERA 2, is divided into four Work Packages (WPs) which reflect the objectives cited in 1.1. Although the four WPs will be explored separately they typically have heavy dependencies. Figure 1 below illustrates the inter-dependencies of each objective and WP, and their link with the HERA 1 work.

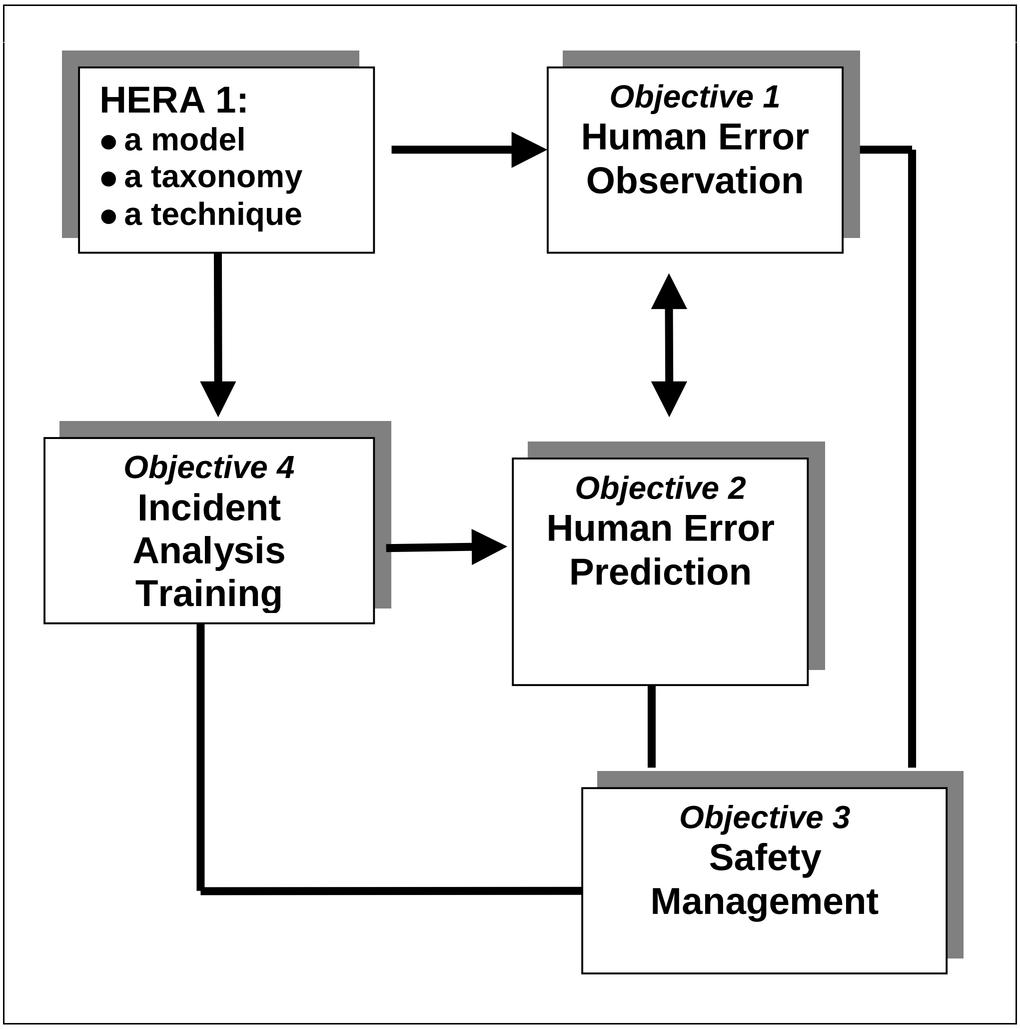

Figure 1: Overall work plan for Phase 2 of the HERA Project

The present work package, WP2, describes the development of an approach and method to predict human errors in the ATC environment. The report describes a two-stage approach in this process:

- firstly, a review of methods which have been used in similar working environments, followed by a proposed methodology for use within the ATM environment;
- secondly, the methodology will be used within the operational environment to predict and verify human error trends, with particular emphasis on the introduction of new technology in support of an existing task activity: Flight Progress Strips (FPS).

Results from both these experiences are detailed and recommendations for future work are discussed.

The remainder of this report contains a number of sections, as follows, and a detailed Appendix providing the HERA-JANUS taxonomies and tables:

- Section 2, 'Predicting Performance in ATM', discusses the prediction of performance in the ATM environment.
- Section 3, 'The Starting Point: HERA-JANUS', details the principles of the original HERA development work.
- Section 4, 'HERA: A Revised Framework Suited to Prediction', discusses a revised framework which is suited to the prediction of human error in ATM.
- Section 5, 'HERA-PREDICT: The Method', provides explanations on the predictive HERA Method.
- Section 6, 'An Example of HERA-PREDICT', uses an example in the ATM environment – FPS – on which to test the proposed predictive technique.
- A Bibliography, Further Reading, the Abbreviations and Acronyms used in the document and their full designations, and a list of those who contributed to the report can be found at the end of this publication.

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2. PREDICTING PERFORMANCE IN ATM

2.1 Introduction

The predictive version of the HERA-JANUS Technique reflects the common observation that performance is determined or driven by the context or the situation as much as by individual or team ‘psychological mechanisms’. This is not meant to deny the existence and effects of psychological functions, whether in the individual or in the group. The point is rather that these psychological functions do not work by themselves, in a vacuum, but that they are subject to the effects of the work situation or the context. While there is clearly variability in both individual and group psychological functions, there is strong evidence that the effects of this variability is far less than the effects of the work environment, hence the context plays a larger role than the personal internal environment. For instance, in all traditional Human Reliability Assessment (HRA) methods, the numerical weight of the Contextual Conditions (CCs) limits the impact of Human Error Probability (HEP). The starting point for the method is that manifest performance failures – here referred to as Error Types – are due to unanticipated variability in the performance of the total ATM system, rather than to specific psychological, technological, or organisational failures. ATCOs are professionals who at all times try to control the traffic as safely and efficiently as possible, and therefore have no intention to deliberately disrupt the traffic.

Air traffic management is by nature a systemic activity, involving ATC centres, flight-deck crews, meteorological services, engineers and others. Claiming that the HERA predictive approach would account for all these entities would certainly be misleading, and striving to do so would probably be over ambitious. However, the issue of an appropriate ‘focal length’, thus of the scope considered by the prediction analysis, should be addressed.

If the entire ATM system is not the most appropriate unit of analysis for error prediction, then the focus might be at the other extreme, namely the individual ATCO. Even though the Planning Controller (PC) and the Radar Controller (RC) roles are *a priori* clearly differentiated, work practice reveals the crucial part played by the interactions existing between the two controllers. In the first place because the way the PC organises the traffic entering the sector obviously affects the RC’s activity, but also because the two controllers for most of the time are working collaboratively. The same team phenomena exist between different groups within the same centre, or between adjacent centres. Therefore, ATC is a team or group activity, whether the various team members are in the same room or interacting remotely, and the overall ATM performance relies on the whole system. Where then should the boundaries be positioned for the system considered in error prediction? Even if a whole centre is an attractive perspective, it remains too wide a scope. Therefore, it must be realised that the present approach can and should be considered as a starting point with opportunities to expand in the future.

2.2 The Scope of Error Prediction

Accident analysis is primarily concerned with finding the causes of something which has happened, starting from the consequences that were observed. Error prediction is primarily concerned with finding out what can or may happen in the future, and is therefore concerned with potential consequences rather than with causes. Accident analysis and error prediction differ fundamentally, and this difference will have consequences for the methods that are used as well as the models and taxonomies that constitute the conceptual basis for the methods.

Most of the engineering or technological approaches to error prediction, such as fault trees apply a bottom-up principle, in the sense that they consider how individual functions and components of a system may fail, and how these failures may propagate to achieve their final consequences. The functions or components can either be considered in relation to the functional or structural topology of the system, or in relation to specific event sequences, usually represented as event trees.

This approach can also be considered with the potential failures that humans may make, by starting from specific (hypothetical) 'Error Mechanisms' that, in accordance with the supporting theory, demonstrate how humans err in the carrying out of an action. However, if the concept of a failure mechanism is taken seriously, it would be more natural to start the prediction by considering how human actions may fail on the level of manifestation, rather than how they may fail in terms of the hypothetical internal mechanisms. This corresponds to a distinction between Error Types and Error Mechanisms.

An **Error Type** refers to the ways in which an action can fail, according to the underlying model or classification system. Thus, in an event tree the two Error Types are 'correct actions' and 'failure to respond'. In the basic human factors classification, Error Types are 'errors-of-omission' and 'errors-of-commission' (Swain & Guttmann, 1983; Hollnagel, 2000). In the more elaborate information processing classification, Error Types are cognitive function failures such as skill-based errors (slips and lapses), rule-based errors (rule-based mistakes) and knowledge-based errors (knowledge-based mistakes) (Reason, 1990).

An **Error Mechanism** refers to the ways in which a performance deviation can manifest itself. The description of Error Mechanism is in this case based on characteristics, such as deviations in timing, in duration, in direction, in force, etc. Over the years a set of well-defined and consistent Error Mechanisms has been developed, and their value has been proven through practice.

For the purpose of the predictive version of HERA, the significant consequences that must be avoided are already known, namely the collision of two aircraft. The prediction can therefore be directed at identifying the error modes that may lead to a collision or to a high risk (likelihood) of a collision. This means that the prediction can be carried out as a directed top-down search, rather than as a bottom-up combination of failures of individual functions and components. The directed search also means that the prediction must start from a description and an understanding of the characteristic work situations, hence a description and understanding of the task and the context. In this sense the prediction method complies with the principles of the current generation of human reliability and human error approaches.

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3. THE STARTING POINT: HERA-JANUS

3.1 Principles of the Classification in HERA-JANUS

The basic principles of the approach developed in the HERA-JANUS Technique are shown in Figure 2.

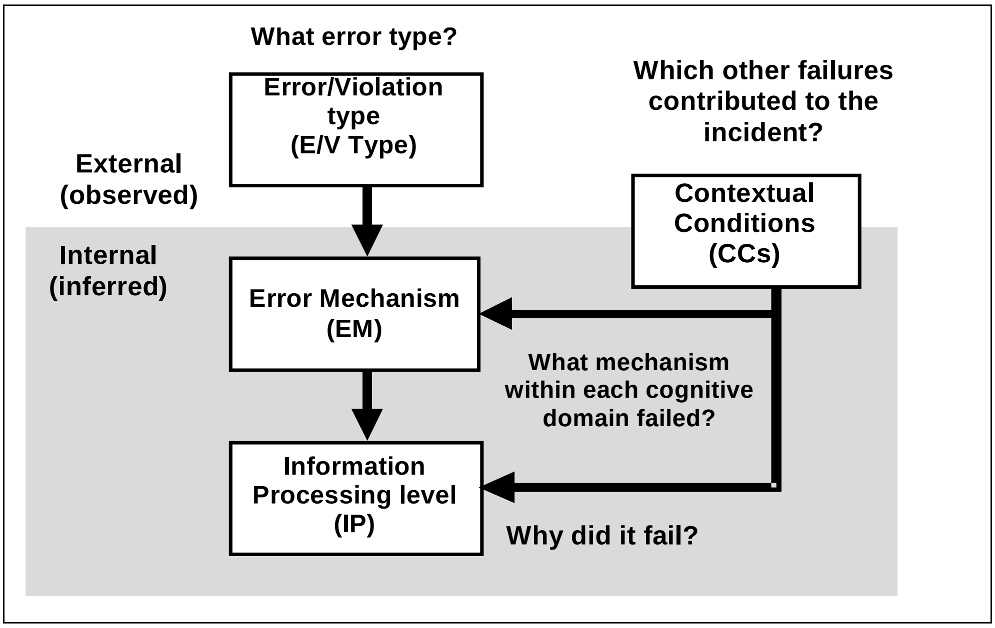

Figure 2: The relationship between Error Types within HERA-JANUS

According to this, the analysis starts from a description of what happened, called the Error, Rule-breaking or Violation type, and finds the possible causes by tracing backwards, according to the principles of the 'spheres of influence' (Figure 3) which corresponds to the common information processing model of human activity.

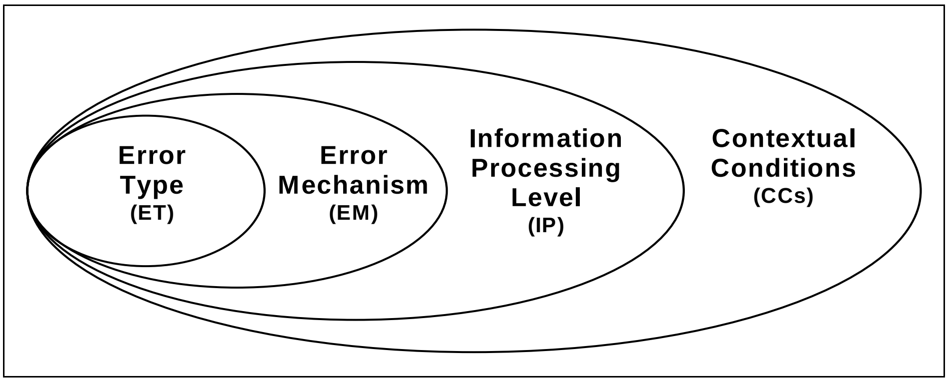

Figure 3: Spheres of influence of ETs, EMs, IPs and CCs

In order to classify errors for incident analysis, the HERA-JANUS Technique emphasises that it is necessary to describe two types of factors, namely:

- **the error**, described in terms of **what** occurred (Error Type), **how** it occurred (Error Mechanisms); and **why** the mechanism failed (information processing levels);
- **the context**, described in terms of **when** the event occurred, **who** were involved, **what** tasks were being performed, **how** the event occurred in time sequence, and **which** information was involved.

To achieve this purpose, the HERA-JANUS Technique uses the classification system shown in Table 1. Here the Error is specified in terms of Error Type, Error Detail, Error Mechanism, and Information Processing level and the Context is further specified in terms of Task, Information, Equipment, and Contextual Conditions.

Table 1: HERA-JANUS classification system

Variable	Class	Description
Error	Error / Rule-breaking / Violation Type	What cognitive domain was implicated in the error?
	Error Detail	What detail can be applied to the error?
	Error Mechanism	What cognitive function failed, and in what way did it fail?
	Information Processing level	Why did the error occur in terms of information processing failure
Context	Task	What task(s) was the controller performing at the time that the errors occurred?
	Information / Topic of error	What was the topic of the error or the information involved (e.g. what did the controller misperceive, forget, misjudge, etc.)? What HMI element was the controller using?
	Equipment	What equipment did the controller error relate to?
	Contextual Conditions	What other factors associated with the controller or the working environment affected the controller's performance?

The cognitive domains were introduced to guide the task of allocating individual Error Types to high-level categories, and to ease the analysts task of finding the applicable category for an observed or reported error when using the classification system. An error detail roughly corresponds to the inferred position of an Error Type within the cognitive architecture, and thus refers to a specific model of human information processing.

The HERA-JANUS Technique defines four cognitive domains, and for each lists the corresponding Error Mechanisms (EMs) and Information Processing levels (IPs), as summarised by Table 2. The Error Mechanisms (EMs) describe the internal manifestation of an error within each cognitive domain, hence the failure of a cognitive function within the domain. The role of the Error Mechanisms (EMs) in the HERA-JANUS Technique is to provide an interface between the Error Types (ETs) and the Information Processing level (IP) in accordance with the underlying information processing model. Information Processing levels in turn describe how psychological causes influence the Error Mechanisms (EMs) within each cognitive domain.

Table 2: Relation between cognitive domains, Error Mechanisms and Information Processing level[1]

Cognitive domain	**Cognitive function**	**Error Mechanisms**	**Information Processing levels**
Perception & Vigilance	▪ Detection ▪ Identification ▪ Comparison	▪ Hearback error ▪ Mishear ▪ Late/No detection ▪ Late/No auditory detection ▪ Late/No visual detection ▪ Misperception ▪ Misidentification ▪ Misread	▪ Visual search failure ▪ Monitoring failure ▪ Expectation bias ▪ Association bias ▪ Visual/Sound confusion ▪ Spatial confusion ▪ Discrimination ▪ Distraction/Preoccupation ▪ Tunnelling ▪ Out of sight bias ▪ Information overload ▪ Vigilance
Working Memory	▪ Recall perceptual information ▪ Previous actions ▪ Immediate/ current action ▪ Prospective memory	▪ Forget to monitor ▪ Forget planned action ▪ Forget to perform action ▪ Forget previous actions ▪ Forget temporary information ▪ Inaccurate recall of information	▪ Mode failure ▪ Memory capacity overload ▪ Similarity interference ▪ Distraction ▪ Preoccupation ▪ Negative transfer of information ▪ Mis stored information
Long-term Memory	▪ Stored information (procedural and declarative knowledge)	▪ No recall of temporary information	▪ Insufficient learning ▪ Rarely used information

1 Full tables relating to these issues can be found in the Appendix

Table 2: Relation between cognitive domains, Error Mechanisms and Information Processing level[2] *(cont'd)*

Cognitive domain	Cognitive function	Error Mechanisms	Information Processing levels
Planning & Decision-making	▪ Judgement ▪ Planning ▪ Decision-making	▪ Misjudgement ▪ Incorrect decision or plan ▪ Late decision or plan ▪ No decision or plan ▪ Insufficient plan	▪ Incorrect knowledge ▪ Lack of knowledge ▪ Integration failure ▪ Failure to consider side effects ▪ Cognitive fixation ▪ Incorrect assumption ▪ Risk recognition failure ▪ Denied risk ▪ Misunderstood communication
Response Execution	▪ Timing ▪ Positioning ▪ Selection ▪ Writing ▪ Communication	▪ Typing error ▪ Selection error ▪ Positioning error ▪ Timing error ▪ Information not transmitted/recorded ▪ Unclear information transmitted/recorded ▪ Incorrect information transmitted/recorded ▪ Omission	▪ Problem of habit ▪ Spatial confusion ▪ Similar look/function ▪ Misarticulation ▪ Manual precision ▪ Intrusion of thoughts ▪ Environmental interruption/ intrusion ▪ Slip of the tongue/pen

The HERA-JANUS Technique also developed detailed tables of the Contextual Conditions[2].

3.2 Evaluation of HERA-JANUS within the ATM Work Situation

It is clear from the above descriptions that the HERA-JANUS Technique placed the focus in two areas of the ATM system, one was the individual user, i.e. a method for analysing – and possibly predicting – errors made by individuals. The second was the context in which the air traffic controller is placed and is concerned with the task, procedures and organisational environment of the ATM system.

3.2.1 The ATM environment

A realistic approach in ATM must begin by acknowledging that controllers work as teams and in teams. Even in small tower environments the controller must be considered part of a team, although a spatially distributed one, and therefore it is necessary that the classification system and the underlying model is capable of representing team factors and team functions.

[2] Full tables relating to these issues can be found in the Appendix

The importance of teamwork and the effects of working in a team were, of course, not disregarded by the HERA-JANUS approach. Indeed, the Contextual Conditions included many that directly or indirectly referred to team functions. This can be seen in Table 3 below:

Table 3: Details of team performance Contextual Conditions

Poor/unclear hand-over /take-over	
Poor/unclear coordination	
Poor communication -pilot, colleagues	
Poor team relations - personality, conflict, pairing	
Returning to sector after break	
Temporary unmanned position	
New/temporary team allocation	
Poor/unclear working methods, responsibility	
Trust in others - over/under/mis	
Inadequate assertiveness	
Team pressure	
Cultural issues	
Duty of care	
Supervisory problems	poor/no planning poor/no decision-making poor/no feedback
Poor/inadequate support from flight data	
Poor/inadequate support from maintenance	
High administrative workload	
Other social and team problems	

Conversely, many of the team factors shown in Table 3 may be considered as likely starting points for error prediction, hence as important as the Error Mechanisms and information processing levels. Acknowledging the collaborative nature of ATM work, it is considered essential to treat team and individual factors with equal importance in a predictive HERA method.

3.2.2 HERA as a basis for prediction

Error analysis and error prediction are fundamentally different. Error analysis starts with the observed events - the Error Type - and tries to identify the likely causes in accordance with the assumptions of the model. Error prediction can, however, not simply reverse the process, i.e. start from the possible causes and work its way forward to external error modes. The reason for this is that the retrograde search is constrained by the facts of the actual situation, which effectively reduces the search tree for irrelevant paths. The conclusion is that prediction therefore must begin by identifying the possible Error Types or manifestations, and use these as a starting point for identifying the most likely ways in which they have evolved. This is described in more detail in Section 4.

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4. HERA: A REVISED FRAMEWORK SUITED TO PREDICTION

4.1 The Link between Retrospective Analysis and Prospective Assessment of Human Error

Often retrospective and prospective methods are discussed as being of different nature. This is certainly true if one focuses on the time line on which they are associated.

Retrospective analysis deals with events which have happened and is following the time line backwards from the event to the underlying causes. This trace back is able to find specific causes or Contextual Conditions that resulted from the event. Another event may have developed differently and followed another path into history as shown in Figure 4.

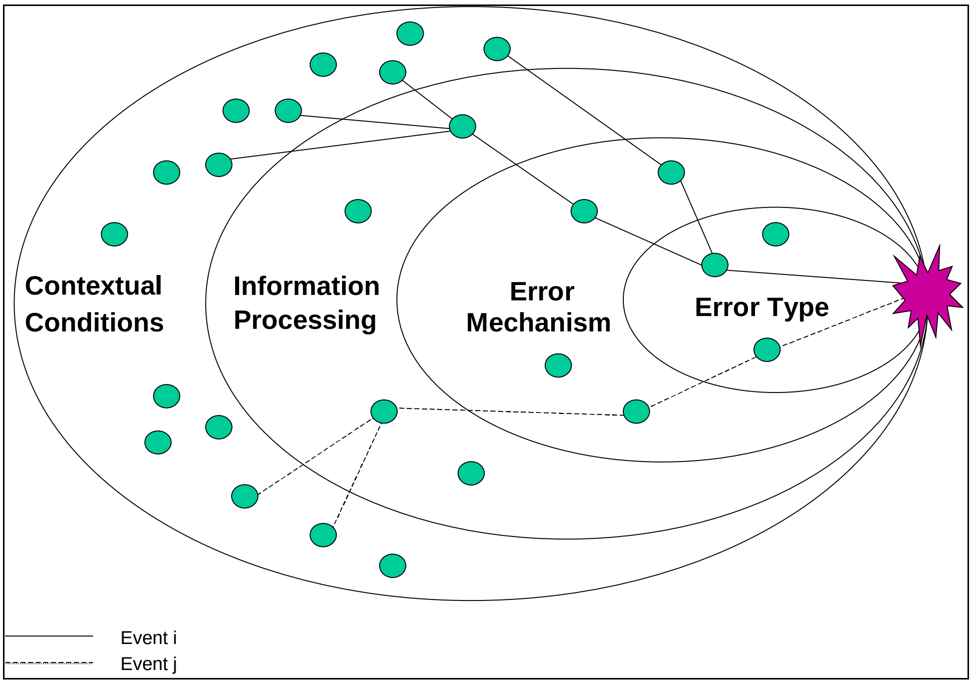

Figure 4: Historical trace from a defined Error Type to the underlying Contextual Conditions

Prospective assessment (see Figure 5) is attempting the prediction of possible future events. Therefore there is not one specific path (or pattern) that is investigated but several possible paths into the future that may develop from a certain set of Contextual Conditions to probable Error Types (i.e. certain human behaviours in a wrong context and with adverse effects on a specific system).

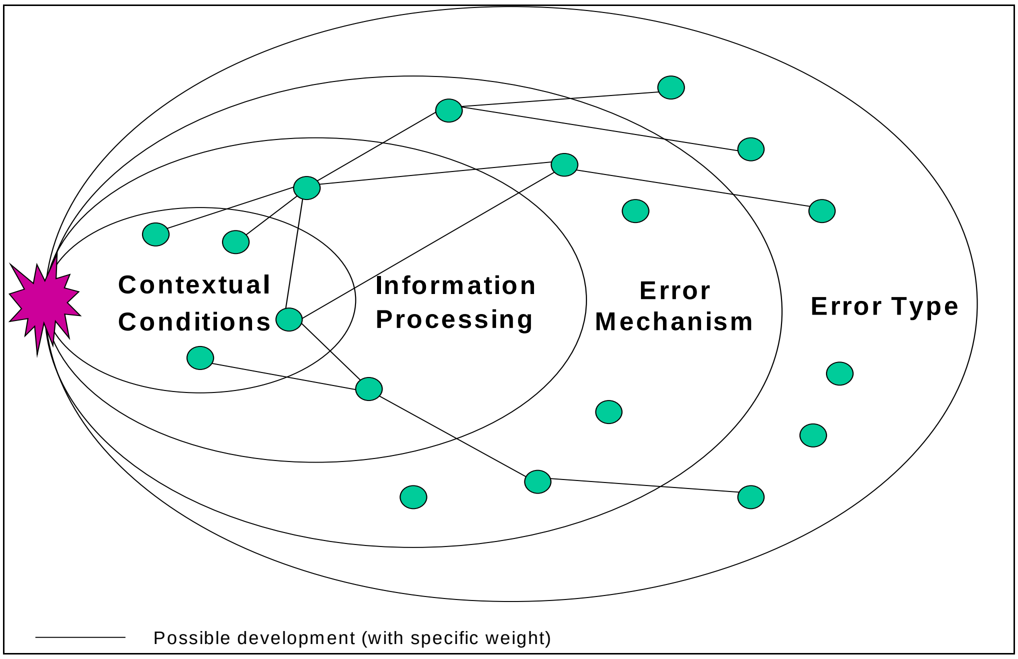

Figure 5: Possible development of one contextual condition to several Error Types

Retrospective tracing back of an event and prospective assessment have major differences. Retrospective analysis always shows a specific path into history while prospective assessment investigates possible paths into the future. Therefore *the direction of analysis* and the *search or analysis scheme* may differ between prospective and retrospective methods (Straeter, Isaac & Van Damme, 2002).

Also the set of possible relations differs from retrospective to the prospective view. While in a retrospective view all the relations between the errors and Contextual Conditions are in principal available, there are always several possible futures in the prospective view. This difference has an impact on the analysis of the task and possible errors (i.e. failures to complete a task).

In terms of data processing we therefore find a one to many relation of human errors to Contextual Conditions in the retrospective view while we find a one to many relation of Contextual Conditions to possible human errors in the prospective view. However, both views also have common elements that are essential for analysis and assessments and that are vital for exploiting past information for prediction, i.e. the results of incident investigation.

4.2 Common Elements of Retrospective Analysis and Prospective Assessment

The most important common elements are the common structure from errors to Contextual Conditions and the common language for describing either analysis results or assessments.

4.2.1 Common structure

Figures 4 and 5 show the distinction of the HERA-JANUS approach for retrospective analysis of incidents and prospective assessment of human error. It distinguishes ‘Error Type’, ‘Error Mechanism’, ‘Information Processing level’ and ‘Contextual Conditions’ (see EATMP, 2003a).

The CAHR (‘Connectionism Assessment of Human Reliability’) approach uses a structure that draws a similar framework with differing content using the levels ‘behavioural error’, ‘cognitive coupling process’, ‘cognitive tendency’ and ‘Contextual Conditions’ (Straeter, 2000). Another approach, known as CREAM (for ‘Cognitive Reliability and Error Analysis Method’), uses an analysis and assessment structure from ‘action failure’, ‘cognitive function failure’, ‘cognitive demands profile’, ‘control mode’ to ‘common performance conditions’ (Hollnagel, 1998).

A final method of comparison, known as ATHEANA (for ‘A Technique for Human Event Analysis’), distinguishes between ‘error forcing contexts’, ‘Error Mechanism’ and ‘unsafe act’ (NRC, 2000).

Generally speaking, all the approaches have a similar underlying structure. The various approaches try to link errors to Contextual Conditions in the retrospective view and in the prospective approach link ‘causes’ via ‘cognitive behaviour’ with ‘behavioural effects’ (see Figure 6).

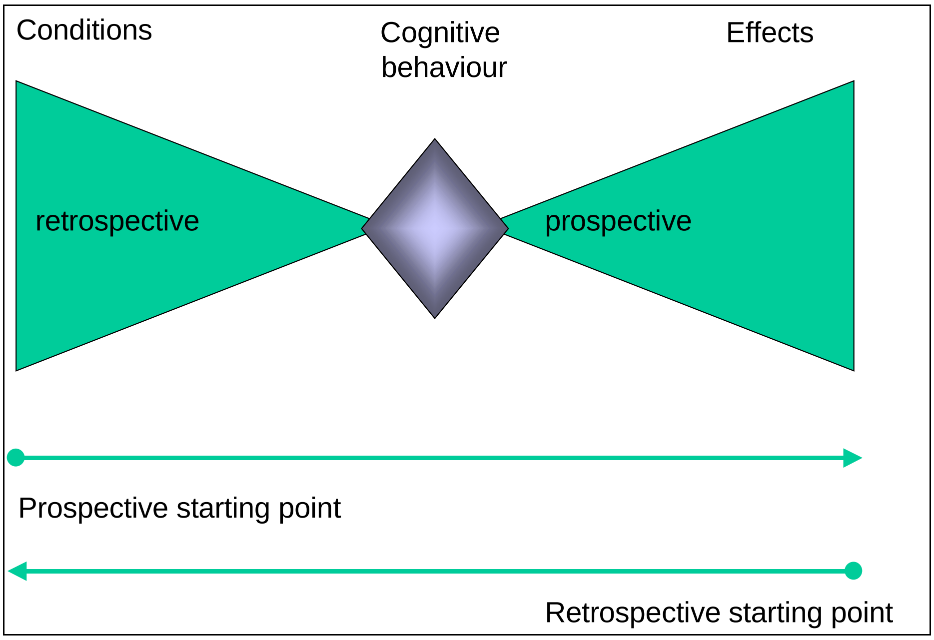

Figure 6: Common basic elements of retrospective and prospective methods

No matter which instance of the basic elements of retrospective or prospective methods one chooses, an essential condition for exploiting past experience gained with a retrospective method, for a prospective assessment, is to use a compatible or at least comparable structure for the event description and the assessment. Whether this instance is correct or not is a discussion that certainly has to be resolved before one chooses a method. It may also be solved according to the rule of requisite variety (Hollnagel, 1998) or be resolved based on the empirical practicability and predictability of the instance chosen, that is by the way the framework is used in real operational environments. It is realistic to expect, however, that a compromise between academic exactness and the actual working environment, should be considered.

4.2.2 Common language

The method used should also provide an approach for finding the language links of retrospective analysis and prospective assessment of human error.

According to the figures, Error Mechanisms (external, internal, psychological) may be the same in an event which has happened as well as in a future event. This coherency of past behaviour and future behaviour is at least the basic assumption of psychology as a science. For instance, the same circumstances or contexts observed as leading to certain Error Mechanisms in a retrospective analysis may also be used as one possible relation for predicting one behavioural path in a future assessment. No matter which common basic elements one chooses, the language (taxonomy) for the event description and the assessment has to be the same, compatible or at least comparable if one wants to have a chance to make reliable and valid predictions.

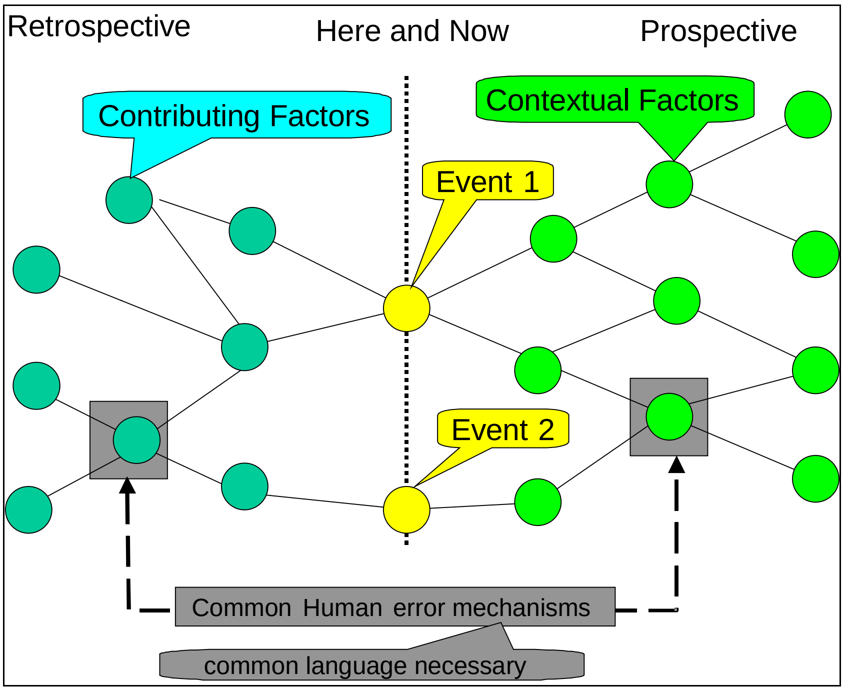

Figure 7: Common language for retrospective analysis and predictive assessment

4.3 Using Retrospective Data for Prediction

Retrospective data only covers a small sub-set of those tasks and circumstances that may be of importance for prospective assessment. However, the more events which are analysed and exploited for prediction the more accurate the data will be. Even a relatively small set of events, 55, has not shown a significant loss of predictive power compared to a set with 165 events (Straeter & Reer, 1998). However, one has to be aware that the set of tasks and conditions contained in a event data-base may always be incomplete and may always lead to uncertainties in prediction. The larger the knowledge and details, the better the prediction based on past experience.

Another uncertainty may arise from the fact that the behaviour of a system to predict human activity is usually not completely known. Both uncertainties may lead to the requirement to cover them by larger or broader categories or by a hierarchy that can cope with the uncertainties.

4.4 Characterisation of Contextual Conditions in HERA-JANUS

As argued in the preceding paragraphs, the model underlying the error prediction method refers to the functional characteristics of individuals as well as teams. As far as the latter is concerned, it cannot be assumed simply that the performance or functioning of the team is the collection of individual's information processing. The experience from studies in team behaviour and small group psychology strongly suggests that it is necessary to use the characteristic functions of a team as a basis. In other words, instead of a model of the 'internal mechanisms' of individual performance enhanced by Contextual Conditions, there is a need to have a corresponding model of the 'internal mechanisms' of group or team performance, even if the team is as small as two members; in principle this also includes cases where the team is distributed in space and time.

A significant part of a team model must consider issues related to communication among team members. Numerous studies of accidents and event reports have shown that communication-related performance determinants play a major role. Examples of these and other team factors are common misunderstandings (shared mental model), group thinking, group biases, mistaken assumptions about others' way of thinking, group pressure, simplification strategies due to shortage of time.

A neutral but detailed description of the situation is preferred to a description exclusively in terms of the Contextual Conditions. This allows the inclusion of both negative and positive team influences. Therefore, in the proposed approach, the characterisation of the situation is not based on known negative aspects, but on a neutral description of the combined characteristics.

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5. HERA-PREDICT: THE METHOD

The method is based on those principles already discussed and the content to be determined is supported by the HERA-JANUS Technique taxonomies and tables and data from incident investigation within Europe.

The method follows a nine-step activity cycle which obviously needs to be adapted to the specific question asked, that is whether the new activities, procedures or systems are completely new or have been adapted. An example would be when the ATM system simply adds a technological support to an already established activity – written to electronic FPS, or when the system adds a completely new functional activity – datalink messaging.

The nine-step activity cycle would be as follows:

1. Undertake a Functional Task Analysis (FTA) on the system[3].

2. Verify the FTA within the operational environment with air traffic controllers and other technical experts depending on the system under analysis.

3. For each identified task, identify the associated HERA-JANUS Contextual Conditions.

4. Undertake an FTA on the changing or changed system.

5. Verify the FTA within the operational environment with air traffic controllers and other technical experts depending on the system under analysis.

6. For each identified task, identify the associated HERA-JANUS Contextual Conditions.

7. Compare the current operational tasks to the changed operational tasks, and list the changes in a change matrix.

8. Undertake a HERA-JANUS Error Detail, Error Mechanism, Information Processing level and Contextual Conditions identification process on all task changes.

9. Establish the risks involved by assessing frequency of task and the severity of occurrence, if known.

The above nine-step activity cycle is illustrated in Figure 8.

[3] If the system is new a descriptive analysis must be performed on the proposed system

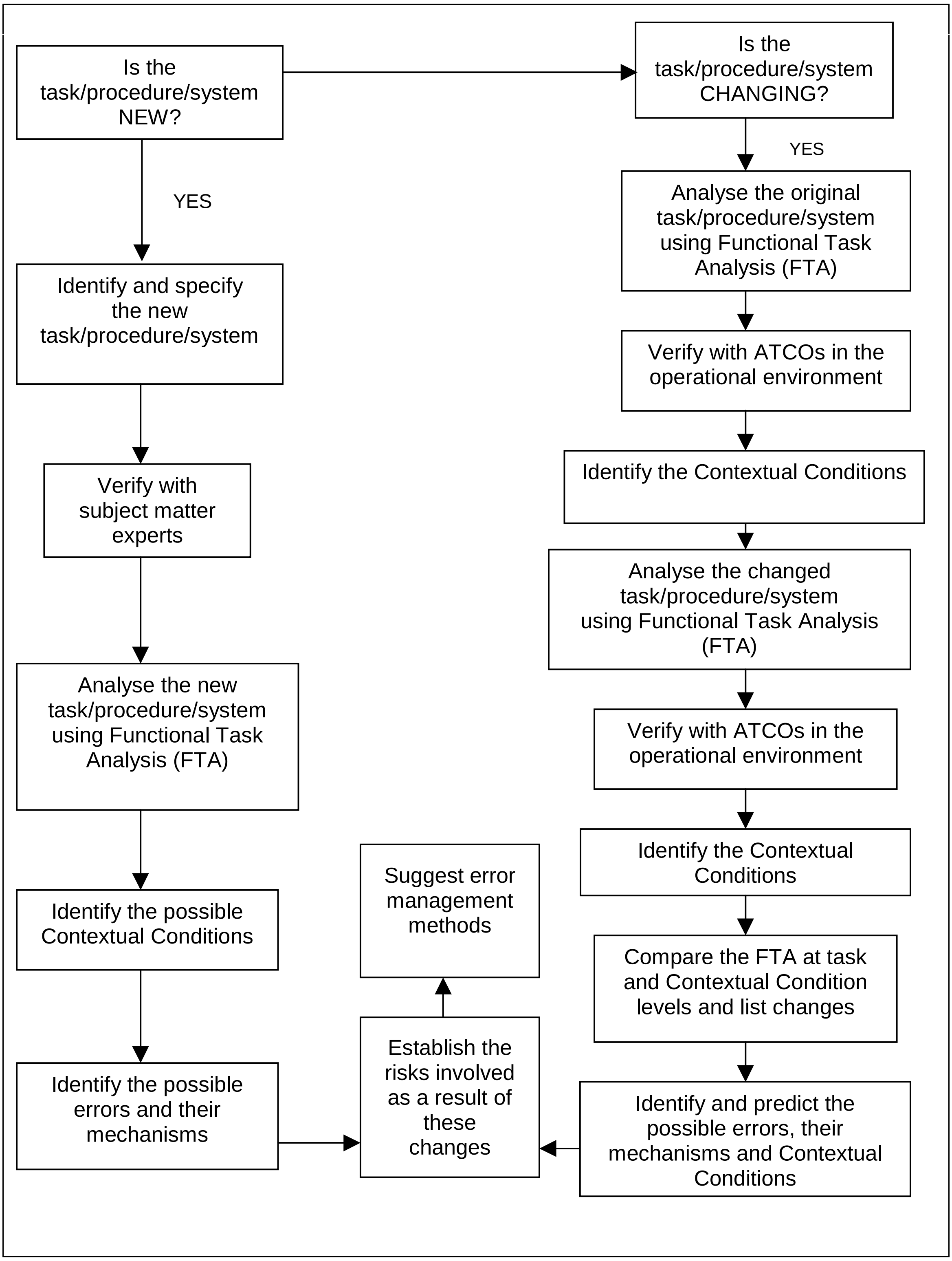

Figure 8: HERA-PREDICT Methodology

6. AN EXAMPLE OF HERA-PREDICT

The development of Flight Progress Strips (FPS) from paper to an electronic medium has been chosen as an example to demonstrate the use of the HERA-PREDICT Method.

It should be noted that this change is an emerging situation and that although there are some ATM systems who have introduced electronic FPS, there are others who still use the paper medium. The selection of the two ATM systems in this example study has allowed the comparison of the two FPS systems in the live setting which would not always be feasible in a changing system, in which typically there would be several development steps and activities. However, it is envisaged that the methodology could be used in both new and proposed changing situation. The fundamental difference would be that the observation of a changing system would normally be undertaken in a simulated environment and not a live setting, to ensure complete safety.

The following sections describe, firstly, the human performance factors associated with FPS use and, secondly, the use of the HERA-PREDICT Methodology in a changed system from a paper system, which has always been in use, to an electronic system, which has been in use for the last few years.

6.1 The Use of Flight Progress Strips in ATM: Human Performance Factors

Flight Progress Strips (FPS) are used in ATM for several specific functions. They, firstly and most importantly, record the movement of an aircraft (a/c) through the airspace. Each a/c will have one, or more, strips which include all the parameters of flight which are important, callsign, type, origin, destination and coordination with other reporting points or centres, height, transponder code and various annotations depicting radio frequencies, Estimated Time Arrivals (ETAs), flight levels, and the number of persons on board.

At this point it is important to know how information is read or heard and recorded on the strips, in both the paper and electronic systems. The transfer of information by the human is, complicated and has many limitations. It also has to be realised that the human in this aviation environment, like most others, deals with the information in three distinct stages, each of which is vulnerable to error:

- Firstly, the controller has to sense or pick up the stimulus. This information is displayed by means of audition, hearing the message from the pilot, or by the printed media, information on the strip.

- Secondly, the human brain then processes this information in the working memory and, because of the ‘laws’ of human cognition, this must be done within a **minute,** or the information will be interfered with, or lost.

- Lastly, the controller will respond to this information either by manual action, annotating the strip/input into computer menu, or speech, instruction or readback to the pilot or controller: and in many cases this response is made in both written and spoken modes.

It should also be realised that the human has preferred ways of dealing with certain types of information. The most effective way of stimulating the verbal faculty of human working memory is with speech, rather than print, and the best mode for communicating with the spatial working memory is with pictures rather than sounds.

Print instruction on a strip or on a screen can describe factual information, aircraft type, as well as convey spatial scenarios; where the aircraft is in relation to the one following, etc. Experiments have shown that instructions in printed format are accepted without qualification as being accurate, especially if they are used as a back up to auditory information, or if they are strategic rather than tactical, and transmitted in non dynamic situations. In a dynamic environment, the temporal requirements are critical. In a fast changing situation where display space is limited, a circuit at a busy training airport, the message will probably have a short ‘on-board’ life. When the workload is high, the temptation by the controller is to cancel or ignore an on-screen written instruction, so it would then be up to the message sender to recognise non-compliance if it occurred.

With increased automation of information there will also be more problems remembering this information. It is known that echoic memory, the ability to recall the sound of spoken words, (even if their meaning is not processed at the time of reception) has a slower decay rate than iconic, the ability to remember symbols such as the printed word.

Having introduced the notion of the human information processing system, and the fact that depending on the information and its use, there are a variety of formats which can be used, the question is what advantage does the written word or icon on a Flight Progress Strip have as an alternative to an electronic presentation with keystroke or touch input entry to change.

Firstly, it must be realised that during the reading of the paper FPS, the controller will usually be touching the relevant information as it is spoken and the written amendment or progress icon will, by its activation of motor pattern, be registering a strong memory trace in the working memory system. In contrast the passive reading of an electronic FPS in a predetermined format, with little opportunity to touch and annotate in a programmed fashion, (key strokes and writing with a pen do not equate in the human information processing system) will reduce the retained information in the working memory. The controller will monitor the information rather than interact with it, which degrades its capacity to be remembered or retrieved accurately from memory later.

The second problem with changing any information on the strips is also concerned with the ease of response. Most controllers can annotate a paper FPS with ease and expedience compared to the highlighting, key stroke response and touch input entry requirements of the electronic FPS, even with considerable practice.

There may also be several other variables linked with this type of display which will change the tasks of the controller. These include:

- the change of sequencing of display which must be programmed *by* the controller not *for* the controller;
- the ability to ‘cock’ a strip for reference (in the physical sense not just visually);
- the permanency of these strips if they need to be referred to at a later date.

There are also more subtle things regarding the paper flight strip which may not have been recognised.

Firstly, the use of the strip to aid and maintain situation awareness. Controllers must have access, in working memory, to a large amount of multi-dimensional data about the past, present, and future status of the aircraft. The paper FPS has become a fundamental part of the controller’s working memory system. Hopkin (1995) states that the paper flight strip *acts as an information display, notepad, memory aid, history and record of action*.

Another important feature of the paper FPS is the fact that as a notepad the controller is capable of reinforcing the memory not only by writing but also by recognising their own writing. It is possible that when controllers read information from a strip in their own handwriting they do not only interpret and comprehend the content, they also remember the previous act of writing it, and perhaps more importantly, the reasons why a particular course of action had been taken. This observation is supported by psychological research on retrieval cues and recent research that demonstrates ‘subject-generated’ memory aids (annotation of to-be-recalled items) which facilitate memory retrieval.

A second area of interest is the use of the strip as a geographical and/or temporal memory prompt. The layout of the strip board, whether it be at a local airport or an oceanic control area, is unique to the flight patterns of that area. Controllers will manipulate the position of their strips to coincide with their geographic and/or temporal sequence of traffic. The movement of strip holders is in accordance with the controller’s management (and training) and is fundamental to the maintenance of their ‘traffic picture’. Each controller will have a different way of handling strips and as they do so they create an action memory trace which is essential to their controlling environment. Additional actions such as holding, tapping, sorting and ‘cocking’ them on the strip board, further facilitates the controller’s understanding and memory for the information displayed. The controllers develop unique ways of sorting and marking (although almost all annotations are standard) that seem to work effectively for each individual.

A third variable which is an essential element of the paper strip system is concerned with ‘prospective memory’, that is memory for to-be-performed activities. In some cases, information for future control actions need only be retained for a short period of time. Recent studies investigating the nature of the representations underlying memory for future actions have found a significant beneficial effect of ‘imaginal-motoric enactment’ of the future activity. This ‘imaginal enactment’ of the future activity is consistent with the research in memory for past activities. This beneficial effect can also be attributed to the multimodal and contextual properties of having actually performed the task, and in addition the intentional (or unintentional) visualisation of the task, which promotes visual and motor encoding.

It is suggested that the process of encoding future activities involves an internal, symbolic enactment of the tasks which enhances memory (Isaac, 1994). This implies that rehearsal, or repeated internal simulation of the procedure to be performed, will enhance memory at the time of use, in much the same manner that maintenance rehearsal retains verbal material in working memory. It is also suggested that if rehearsal takes advantage of the modality-specific properties of the future task, not only will memory for content be enhanced, but memory retrieval cues will be enhanced under proper conditions. This can be illustrated from the following extract from a controller in an interview.

> It’s a question of how you read those strips … An aircraft has called and wants to descend, now what the hell has he got in his way? And you’ve got ping, ping, ping, those three, where are those three, there they are on the radar. Rather than looking at the radar, one of the aircraft on there has called, now what has he got in his way? Well, there’s aircraft going all over the place, now some of them may not be anything to do with you … Your strips will show you whether the aircraft are above or below them, … or what aircraft are below you if you want to descend an aircraft, and which will become a confliction. You go to those strips and you pick out the one that is going to be in conflict if you descend an aircraft, and look for those on the radar and you put them on headings of whatever, you find out whether those, what those two are ….. which conflict with your third one. It might be all sorts of conflicts all over the place on the radar, but only two of them are going to be a problem, and they should show up on my strips.

The ‘moving’ radar screen is, from an interpretative point of view, relatively static, while the ‘fixed’ hard copy strips are relatively dynamic. For ATC tactical operations, planned actions are found in the FPS and past actions are reflected in feedback on the radar and flight strip markings.

The last important variable to mention is related to memory codes, particularly motoric encoding and its ‘generation effect’. The ‘generation effect’ refers to the fact that information actively and ‘effortfully’ generated is more memorable than passively perceived information. This is from research which has revealed that one remembers more by doing and that some kind of active or effortful involvement of the person in the learning process is more beneficial than merely passive reception of the same information. This 'generation effect' has direct relevance to ATC tactical operations, where the active integration of the controller's information processing capabilities with relevant support systems (FPS and radar) is fundamental to the integrity of the understanding and memory of the traffic situation.

There is research evidence that controller's memory for flight data is a function of the level of control exercised. It has been found that flight information for aircraft in possible conflict is significantly better than memory for flight information for those aircraft of less concern at that moment in time and which require little controller intervention (Isaac, 1995). As well as enhancing information recall, handling strips helps the controller to organise work and resolve problems, particularly regarding future plans. The physical act of moving the strips from pending to active bays or touching those strips to be annotated involves a review of knowledge and previous decision. This helps enhance the controller's 'picture' and writing on the Flight Progress Strips seems to be more memorable than watching an automatic updating of information as would happen in an electronic flight display system.

6.2 Using the HERA-PREDICT Methodology

The basic HERA-PREDICT Method has been described in Section 5 with a nine-step activity cycle and illustrated in Figure 8. Each step will be described and discussed in more detail in the following sections, using the development of Flight Progress Strip technology as an example in the ATM system. At each step there was extensive discussion, observation and consultation with several subject matter experts; air traffic controllers, incident investigators and survey specialists, within the two ATC organisations chosen for this work.

Step 1: A Functional Task Analysis (FTA) with regard to paper Flight Progress Strips (FPS) was undertaken with the following results:

Function 1: Provide information about aircraft and verification

- action: put FPS in the correct colour holder depending on type of traffic
- action: place the FPS on the FPS board/bay at the correct place
- action: mark FPS

Function 2: Sort aircraft by several criteria

- action: put FPS in the correct colour holder depending on the type of traffic
- action: place the FPS on the FPS board/bay at the correct place
- according to colour
- according to time speed and/or level
- according to direction (inbound/outbound/crossing)
- according to type (wake turbulence)

Function 3: Support controller's memory[4]

- action: mark FPS
- action: physically touch FPS
- action: flag FPS
- action: place across active FPS board/bay
- action: remove from FPS board/bay

Function 4: Support creating and maintaining 'traffic picture'

- action: collecting data from FPS
- action: interpreting/correlating data from FPS
- action: moving FPS

Function 5: Highlight aircraft with problem

- action: flag FPS
- action: mark FPS with different colours[5]

Function 6: Support communication with team members

- action: point at FPS with finger
- action: handing over FPS to colleague
- action: mark FPS
- action: mark FPS with other colour

Function 7: Provide backup assistance for the system

- radar failure (procedural control support)
- radar screen failure (procedural control support)
- other system failures
- retrieval of information for incident investigation, billing
- storage of information

Step 2: Verification with ATCO's in the operational environment:

Verification and observation were undertaken in the Belgium ATM system over one-, six-hour period in August 2002. The results of this activity can be seen in Table 4.

4 The functions of 'support controllers memory 'and 'creation and maintenance of the traffic picture' are extremely inter-related. The latter needs ATC professionals' support to interpret.

5 Optional and with individual differences

Table 4: Observation and frequency analysis - Paper FPS

Venue: Belgium *Position:* East High/Lux *Date:* 23/08/02 *Time:* 08:00-14:30

Function 1: Provide information about aircraft	**RC[6]**	**PC**
action: put FPS in the correct colour holder depending on type of traffic	18	23
action: place the FPS on the FPS board/bay at the correct place	13	26
action: mark FPS	17	22
Function 2: Sort aircraft by several criteria		
action: put FPS in the correct colour holder depending on the type of traffic		8
action: place the FPS on the FPS board/bay at the correct place – colour/time/direction/type	5	15
Function 3: Support controller's memory		
action: mark FPS	66	14
action: physically touch FPS	5	4
action: flag FPS		
action: place across active FPS board/bay		
action: remove from FPS board/bay	37	25
Function 4: Support creating and maintaining 'traffic picture'		
action: collecting data from FPS	36	8
action: interpreting/correlating data from FPS	38	
action: moving FPS	2	11
Function 5: Highlight aircraft with problem		
action: flag FPS	1	1
action: mark FPS with different colours		
Function 6: Support communication with team members		
action: point at FPS with finger	1	20
action: handing over FPS to colleague	4	25
action: mark FPS	5	4
action: mark FPS with other colour		
Function 7: Provide backup		
radar failure ✓ radar screen failure ✓ other system failures ✓ retrieval of information for incident investigation, billing ✓ storage of information ✓ OTHER: *Usually in Comms failure* *Storage for 3 months*		

The observations and frequency analysis demonstrated that there was a clear, but no absolute, division of labour between the Radar Controller (RC), the Planning Controller (PC) and the flight data assistant. The flight data assistant and PC prepared the Flight Progress Strips (FPS) and holders for the RC. The RC handled, annotated and placed all FPS in the flight progress bays/boards and also used the radar screen to support their work.

The most frequent activities were associated with the actions which 'Supported the controller's memory' – 151, followed by the function to 'Provide

[6] The two columns on the far right of this table represent the activities of the Radar Controller (left), and the Planning Controller and flight data assistant (right).

information about aircraft' – 119 and the functions associated with 'Supporting the creation and maintenance of the traffic picture' – 95. The 'Support communication with team members' listed 59 activities, 'Sorting aircraft by criteria' - 28 and finally 'Highlighting aircraft with problems' – two activities.

The division of activities between the PC and RC were seen most clearly in the 'Support controller memory' where the RC did most activity, the 'Support creating and maintaining the traffic picture' where again the RC was most involved and finally in the 'Support communication with team members' actions where the PC did most activity.

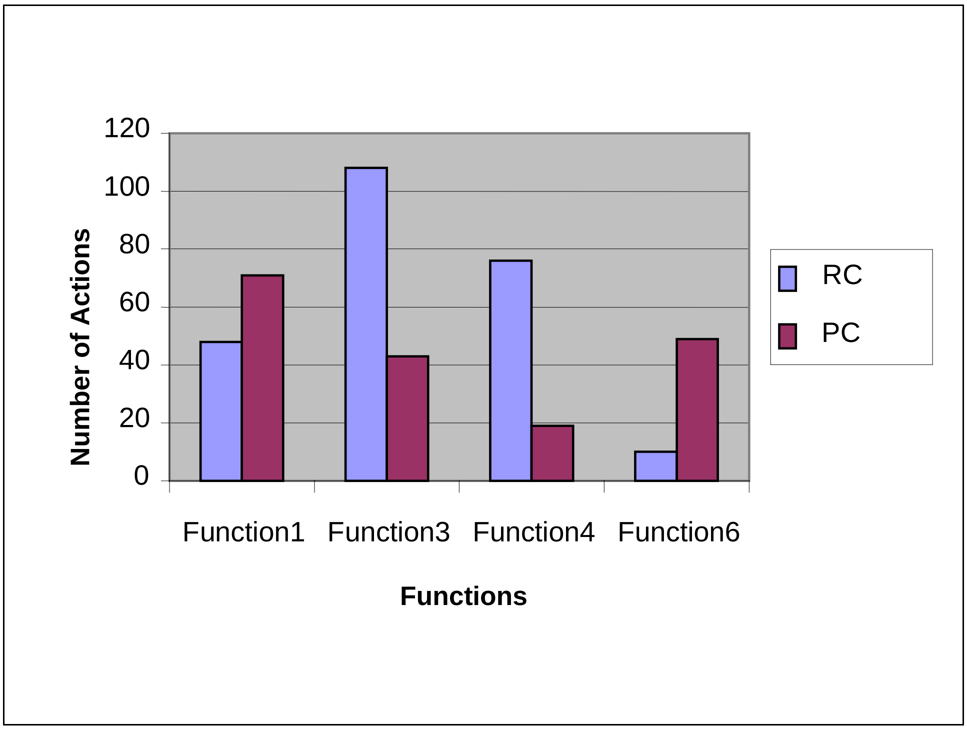

Figure 9: Distribution of functions in paper FPS environment

Step 3: Identification of the Contextual Conditions in the operational environment:

The Contextual Conditions which were associated with the above functions included:

- adequate equipment availability – paper strips, holders, strip bay/boards, pen;
- flight data support in terms of personnel;
- allocation of team functions and responsibilities;
- Team Resource Management (TRM) issues;
- adequate data storage facilities.

Step 4: A Functional Task Analysis (FTA) with regard to electronic Flight Progress Strips (FPS)[7] was undertaken with the following results:

Function 1: Provide information about aircraft and verification

- action: automatic display of strips and flight labels

Function 2: Sort aircraft (a/c) by several criteria

- action: input[8] change of runway configuration
- action: input time which alters the sequencing – estimates or changes
- action: delete flight data label

Function 3: Support controller's memory[9]

- action: highlight flight with light pen
- action: alter flight information via Touch Input Device (TID)
- action: automatic label orientation
- action: delete FPS

Function 4: Support creating and maintaining 'traffic picture'

- action: collecting data from FPS[10]
- action: interpreting/correlating data from FPS and flight data label
- action: moving FPS

Function 5: Highlight aircraft with problem[11]

- action: flagged on flight data label

Function 6: Support communication with team members

- action: point at a/c through flight data label on screen
- action: handing over a/c to colleague
- action: mark a/c through flight data label on screen

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[7] All electronic FPS are displayed on PVD screen.

[8] Electronic light pen and TID.

[9] The functions of 'support controllers memory 'and 'creation and maintenance of the traffic picture' are extremely inter-related. The latter needs ATC professionals' support to interpret and there will be, by implication, individual differences.

[10] The RC and PC positions follow a rather different division of labour in this environment, as the RC relies more heavily on the planning activities of that controller, whilst concentrating on the separation of traffic with less interaction with the strips. This arrangement demands that the PC is more focussed on the strips displayed and more proactive in planning activities in order to take away that workload from the RC. The PC has more FPS records of TMA, other airports and over-flights. The RC and PC also work on a different radar range – the PC has a wider 'range' than the RC.

[11] The actions defined are systems related and therefore vary.

Function 7: Provide backup assistance for the system[12]

- radar failure – heading /level/speed only retained
- radar screen failure – EDD is available
- other system failures - degraded failure allows information to be retained depending on the failure
- retrieval of information for incident investigation, billing

Step 5: Verification with ATCOs in the operational environment:

Observation and verification was undertaken in the Netherlands ATM system over two, 2 1/2 hour periods in January and April 2003. The first visit was to verify the functions and the second was to record the frequency of activity. The results of these activities can be seen in Table 5 below.

Table 5: Observation and Frequency Analysis – Electronic FPS

Venue: The Netherlands Position: Schiphol Approach Date: 21/01/03 Time: 09-11:30
09/04/03 09-11:50

Function 1: Provide information about aircraft	RC- D[13]	RC-A	PC
action: automatic display of strips and flight labels			54
Function 2: Sort aircraft by several criteria			
action: input change of runway configuration			2
action: input time which alters the sequencing – estimates or changes			
action: delete flight data label			
Function 3: Support controller's memory			
action: highlight flight with light pen	501	194	38
action: alter flight information via TID	1010	109	2
action: automatic label orientation			
action: delete FPS			
Function 4: Support creating and maintaining 'traffic picture'			
action: collecting data from FPS		5	92
action: interpreting/correlating data from FPS and flight data label			97
action: moving FPS			2
Function 5: Highlight aircraft with problem			
action: flagged on flight data label			
Function 6: Support communication with team members			
action: point at a/c through flight data label on screen			2
action: handing over a/c to colleague			1
action: mark a/c through flight data label on screen			
Function 7: Provide backup			
radar failure ✓ radar screen failure ✓ other system failures ✓ retrieval of information for incident investigation, billing ✓ storage of information ✓ OTHER: *Storage for 30 days*			

[12] If the system fails, controllers can change working position.

[13] The three columns on the far right of this table represent the activities of the RC – departure (left), radar controller – arrivals (centre) and PC (right).

The observations and frequency analysis demonstrated that there was a very clear division of labour and tasks between the Radar Controller (RC) (arrival and departure) and Planning Controller (PC). There was no flight data assistant position in this system. As a result all Flight Progress Strips (FPS) automatically appear on the monitor of the PC's position and those of the active radar positions.

The division of activities were as follows: the PC was responsible for all aircraft (a/c) in the TMA which were arriving, departing and over-flying. Their responsibility was to sequence all the a/c for the most expeditious flow into and out of the area, according to the runways in use and the appropriate Standard Instrument Departures (SIDs). The PC had all electronic FPS displayed on a monitor and a full radar screen displaying all aircraft under their responsibility. The arrival and departure controllers had the same electronic FPS displayed on monitors as well as a full radar screen, although these displays only indicated the a/c under their responsibility (arrival or departure).

The most frequent activities were associated with the actions which 'Supported the controller's memory' – 1,854, followed by the functions associated with 'Supporting the creation and maintenance of the traffic picture' – 196. The function to 'Provide information about aircraft' was associated with 54 machine-generated actions. The 'Support communication with team members' listed three activities and 'Sorting aircraft by criteria' two activities.

The division of activities between the PC and RC (both arrival and departure) were seen most clearly in the 'Support controller memory' where the RC did most activity, - 1,814 actions versus forty actions of the PC. The 1,814 actions were divided between the action 'highlight flight with light pen (695 actions) and alter flight information via Touch Input Device (TID) (1,119 actions).

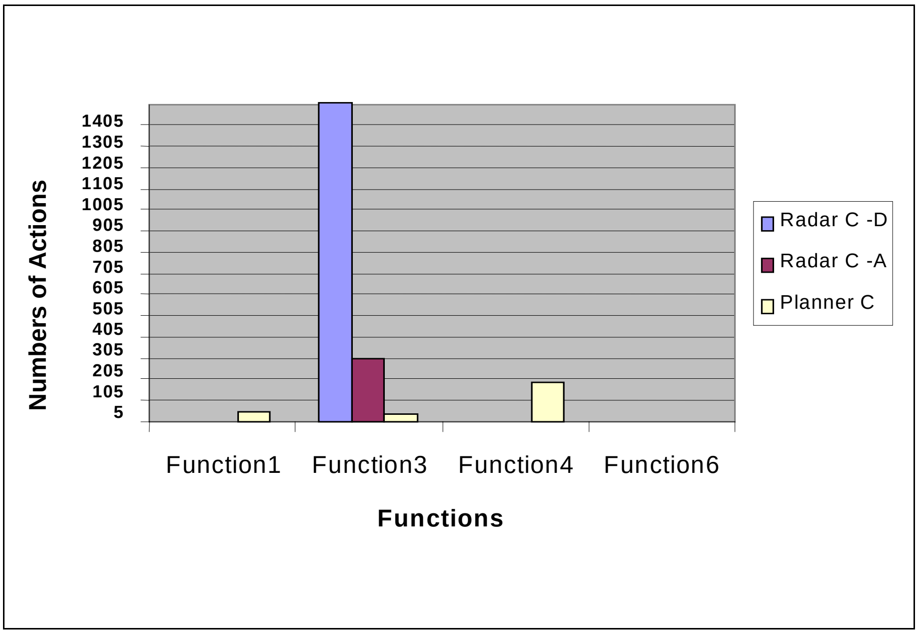

Figure 10: Distribution of functions in electronic strip environment

Step 6: Identification of the Contextual Conditions in the operational environment:

The Contextual Conditions which were associated with the above functions included:

- adequate and reliable equipment – automatic machine generated display and touch input devices;
- allocation and understanding of team functions and responsibilities;
- TRM issues – clear divisions of responsibility and trust;
- adequate data storage facilities.

Step 7: Comparison of the Functional Task analyses and Contextual Conditions and list changes:

Table 6: The HERA-PREDICT functional task matrix

Present system - paper Flight Progress Strips				Future system - electronic Flight Progress Strips			
Function	**Activity**	**Observed**	**CCs**	**Function**	**Activity**	**Observed**	**CCs**
1. Provide information about aircraft	put in holder place on board mark strip	✓ ✓ ✓	equipment available flight data support	**1. Provide information about aircraft**	system generated and displayed	✓	data input information equipment display
2. Sort aircraft by several criteria	place in holder place on board/ bay	✓ ✓	equipment available flight data support	**2. Sort aircraft by several criteria**	change of runway configuration input time which alters the sequencing - estimates or changes	✓ ✓	data input information knowledge equipment display
3. Support controllers memory	mark FPS touch FPS flag FPS place across board/bay remove from board/bay	✓ ✓ ✓ ✓ ✓	equipment available and team allocation team allocation team allocation team allocation team allocation	**3. Support controllers memory**	highlight flight observe automatic label orientation delete FPS	✓ ✓ ✓	equipment available, legible and correct equipment available, legible and correct equipment available and correct

Present system - paper Flight Progress Strips				Future system - electronic Flight Progress Strips			
Function	**Activity**	**Observed**	**CCs**	**Function**	**Activity**	**Observed**	**CCs**
4. Support and maintain traffic picture	collect data from FPS interpret/ correlate data from FPS move FPS	✓ ✓ ✓	RC RC RC	**4. Support and maintain traffic picture**	collecting data from FPS interpret/ correlate data from FPS move FPS	✓ ✓ ✓	PC PC equipment available and correct
5. Highlight aircraft with problem	flag FPS mark FPS with different colour	✓ ✓	RC team allocation	**5. Highlight aircraft with problem**	flag radar label	✓	equipment available and correct
6. Support communication with team members	point at FPS with finger hand FPS to colleague mark FPS mark FPS with colour	✓ ✓ ✓ ✓	RC RC and team RC team allocation	**6. Support communication with team members**	point out FPS through radar label hand FPS to colleague mark FPS through radar label	✓ ✓ ✓	equipment available and correct equipment available and correct equipment available and correct

Present system - paper Flight Progress Strips				Future system - electronic Flight Progress Strips			
Function	**Activity**	**Observed**	**CCs**	**Function**	**Activity**	**Observed**	**CCs**
7. Provide backup assistance for the system	radar failure radar screen failure other systems failure retrieval of data for investigation/ billing storage of information	✓ ✓ ✓ ✓ ✓	equipment available equipment available equipment available data storage data storage	**7. Provide backup assistance for the system**	radar failure radar screen failure other systems failure retrieval of data for investigation/ billing	✓ ✓ ✓ ✓	information available information available information available data storage

The HERA-PREDICT functional task matrix was checked by both operational controllers and safety survey specialists. Once this step had been completed the following step could be undertaken.

Step 8: Identify and predict the possible errors, their mechanisms and Contextual Conditions:

In order to identify and predict the possible errors, their mechanisms and Contextual Conditions, the HERA-JANUS taxonomies and tables were used. These can be found in the Appendix.

Table 7: The HERA-PREDICT change matrix

Paper flight strips	Electronic flight strips	Prediction Comments		
Activity	**Activity**	**Changes**	**Probable Error list**	**Contextual Conditions**
1. put in holder place on board mark strip	system generated and displayed	manual to automatic	*Perception and Vigilance* - misread, failed to detect visual information/or detected it late, too much information *Memory* - forget to perform action, no or inaccurate recall of temporary information	*HMI* - visual display paper to screen –clarity and integrity *Team Factors* - team coordination - data input remotely to flight data physically close
2. place in holder place on board/ bay	change of runway configuration input time which alters the sequencing –estimates or changes	manual to automatic manual to touch input and automatic calculation	*Response Execution* - selection errors, omission of action *Memory* - forget to perform action or forget a planned action	*HMI* - visual display paper to screen – correct, clear and trustworthy *Team Factors* - PC only *Communication* - within the team

Paper flight strips	Electronic flight strips	Prediction Comments		
Activity	**Activity**	**Changes**	**Probable Error list**	**Contextual Conditions**
3. mark FPS touch FPS flag FPS place across board/bay remove from board/bay	highlight FPS and flight data label observe automatic label orientation delete FPS	manual to touch input no equivalent manual to passive attention manual to touch input	*Response Execution* - from slip of the pen to selection errors, omission of action, timing error *Perception and Vigilance* - misread, failed to detect visual information/or detected it late *Memory*- forget to perform action or forget a planned action	*HMI* - visual display paper to screen – correct, clear and trustworthy *Team Factors* - PC only *Communication* - within the team *Environment* - interruption
4. collect data from FPS interpret/ correlate data from FPS move FPS	collecting data from FPS interpret/ correlate data from FPS move FPS	PC v RC PC v RC manual to touch input	*Perception and Vigilance* - misreading, failed to detect visual information/or detected it late, no/late visual information identification, visual search failure, misperception or monitoring failure *Response Execution* - selection errors, omission of action	*HMI* - information display from paper to screen – correct, clear and trustworthy *Team Factors* - PC only *Communication* - within the team
5. flag FPS mark FPS with different colour	flag radar label	manual to touch input no equivalent	*Response Execution* - from slip of the pen to selection error, omission of action *Memory* - forget to perform action, mis-recall/no recall of information	*HMI* - information display timely, correct, clear and trustworthy

Paper flight strips	Electronic flight strips	Prediction Comments		
Activity	**Activity**	**Changes**	**Probable Error list**	**Contextual Conditions**
6. point at FPS with finger hand FPS to colleague mark FPS mark FPS with colour	point out FPS through radar label hand FPS to colleague mark FPS through radar label	manual to touch input manual to touch input manual to touch input no equivalent	*Response Execution* - selection error, incorrect or no information transmitted, omission of action *Memory* – forget to perform action, mis-recall/no recall of information	*HMI* - information display timely, correct, clear and trustworthy *Team Factors* - cooperation and understanding of tasks *Communication* - within the team *Environment* - distraction
7. radar failure radar screen failure other systems failure retrieval of data for investigation/billing storage of information	radar failure radar screen failure other systems failure retrieval of data for investigation/billing	degrees of loss of data degrees of loss of data degrees of loss of data degrees of loss of data different time frame	*Planning and Decision-making* – misjudge aircraft projection, insufficient plan, information integration failure, failure to consider side effects	*HMI* - degraded radar information and FPS from full strip information *Documentation and Procedures* - storage from 3 months to 30 days

Step 9: Establish the risks involved by assessing frequency of task and the severity of occurrence, if known:

In order to attempt to establish the risks involved in the changes identified, the principles used in safety management should be adopted. In the area of safety science, risk is calculated as the addition of frequency of an incident and the severity of its outcome.

The following table took all the relevant data from observations (Tables 4 and 5) and the severity details from incident investigation (Appendix) to create a risk matrix of changed functions and actions.

The frequency was based on a four-point numerical scale one-four, (one equating to low numbers of actions, two equating to a medium number of actions, three equating to a high number of actions and four equating to a very high number of actions). All the data supporting this categorisation can be found in Tables 4 and 5.

The severity ratings were based on the information found in Table 6 and correlated with incident investigation results (Appendix). The severity ratings were calculated on the same four-point numerical scale as the frequency data one-four, which can be seen in Table 7 (one equating to low severity, two equating to medium severity, three equating to high severity and four equating to very high severity).

The average across the errors and Contextual Conditions were calculated and added to the frequency to give a risk rating. The risk was therefore determined by adding the figures for frequency and severity. This gave the following severity scale: two equalled low risk, four equalled a medium risk, six equalled a high risk and eight equalled a very high risk. Where a risk figure fell between two ratings, both were given, i.e. a figure of 3.3 would be given a medium/low rating, medium being the most representative.

Table 8: Risk matrix associated with changed functions and actions

Note: The use of italics and colour codes throughout this table is to assist the decision-making about the most frequent and severe issues. Data from many incident investigation activities within Europe have suggested the most prevalent and severe issues associated with the ATM system. These are coded as follows: black italics indicates a low level of prevalence and /or severity, blue indicates a medium level of prevalence and/or severity and red a high level of prevalence and/or severity.

Function	Frequency	Severity: Error	Severity: Contextual Conditions	Risk
1. Provide information about aircraft	High	- *misread - 1* - *failed to detect visual information - 3* - *detect visual information late - 3* - *information overload - 1* - *forget to perform action - 1* - *no or inaccurate recall of temporary information - 2*	- *HMI – information display, clarity and integrity- 3* - *Team factors – team coordination -3*	***MEDIUM* / HIGH**
2. Sort aircraft by several criteria	Low	- *selection errors - 2* - *omission of action -1* - *forget to perform action -1* - *forget a planned action –2*	- *HMI – information display, timely, correct, clear and trustworthy- 3* - *Team factors – PC -2* - *Communication – within the team -2*	***MEDIUM* / LOW**
3. Support Controller's memory	Very high	- *selection errors - 2* - *omission of action -1* - timing errors -0 - *misread - 1* - *failure to detect information - 3*	- *HMI – information display, correct, clear and trustworthy- 3* - *Team factors – PC -–2* - *Communication within team -2* - *Environment – interruption -3*	**HIGH/VERY HIGH**

Function	Frequency	Severity Error	 Contextual Conditions	Risk
		- *detect visual information late - 3* - *forget to perform action -1* - *forget planned action - 2*		
4. Support creating and maintaining traffic picture	High	- misread -1 - *failure to detect information -3* - *detect visual information late -3* - *no/late visual identification -2* - *visual search failure -2* - misperception -0 - *monitoring failure -3* - *selection errors -2* - *omission of action –1*	- *HMI – information display, correct, clear and trustworthy- 3* - *Team factors – PC –2* - *Communication within team –2*	**HIGH/*MEDIUM***
5. Highlight aircraft with problem	Low	- *selection errors -2* - *omission of action -1* - *forget to perform action -1* - *mis-recall/no recall of temporary information -2*	- *HMI – information display, timely, correct, clear and trustworthy- 3*	**LOW**
6. Support communication with team members	Medium	- *selection errors -2* - *incorrect information transmitted -3* - *no information transmitted -1* - *omission of action -1*	- *HMI – information display, timely, correct, clear and trustworthy - 3* - *Team factors – cooperation and understanding of tasks -3* - *Communication – within the team -2*	***MEDIUM***

Function	Frequency	Severity Error	 Contextual Conditions	Risk
		- *forget to perform action -1* - *mis-recall/no re-call of temporary information -2*	- *Environment – distraction –3*	
7. Provide backup assistance for the system	Cannot be predicted without failure data	- *misjudge aircraft projection -2* - *insufficient plan -1* - *information integration failure -2* - *prospective memory failure -2*	- *HMI – degraded radar information and FPS from full strip information -2* - *Documentation and Procedures – storage from 3 months to 30 days* -1	Depending on the failure – see specific Contextual Conditions for reference

6.3 Findings

From the results of this exercise it can be seen that the highest risk area is concerned with Function 3: support controllers memory. With a change from paper to electronic Flight Progress Strips (FPS) it would seem that several actions can create potential errors, particularly in the perception and vigilance area concerned with the detection of visual information. The other two vulnerable areas appear to be in memory: forgetting planned actions and response execution, and selection errors. The Contextual Conditions which are of concern are associated with the HMI; display features, and the environment; interruption. Both communication and team activity are elements which change dramatically from paper to electronic FPS use and these differences should also be acknowledged.

The second highest risk area can be found in Function 4: support creating and maintaining traffic picture. The errors highlighted in this activity are all concerned with perception and vigilance issues; failure to detect information, detecting visual information late and monitoring failures. The Contextual Conditions which are most at risk in this changed system are concerned with HMI; the correct, clear and trustworthy display of information.

The third highest risk area is seen in Function 1: provide information about aircraft. The highest risks are again in the perception and vigilance area; failure to detect information and detecting visual information late. The contextual condition risks are associated with HMI; information display and team factors; coordination between those responsible for the display and use of the strip.

6.4 Conclusions

The change from paper to electronic FPS is a changing situation in which each ATM provider will have several choices in not only the actual technology to be used, but also the division of activities between the radar and planning controllers. The example given in this work is just one example of such a system and although no two systems can necessarily be compared exactly, the findings should be able to be generalised to similar changes.

The work to establish the HERA-PREDICT Technique has had several expert discussions and observation opportunities and as such has had input from safety scientists, controllers, incident investigators and safety survey personnel. The overall findings of the work have indicated a workable model and process which can be used in both new and changing systems.

The specific findings in the example chosen should be considered a strong indication of the impact on both the human performance and the Contextual Conditions of this change from paper to an electronic medium. However, it should also be recognised that the example was one study and that particularly when considering the human in the ATM system, the outcome is fraught with potential difficulties, since the human manifests large variability.

Having said this it was interesting to note that some critical factors regarding human performance issues - Section 6.1 could be found in the some of the findings detailed in Section 6.2; in particular the way in which information is processed via written or touch input actions.

The most dramatic findings in this study were associated with not only the new method of display and interaction with the Flight Progress Strips, but with the division of tasks between the radar and planning controllers. This is illustrated most clearly in the graphs of action frequencies (Tables 4 and 5). The division of labour between the radar and planning controllers is much more strict in the electronic FPS system and in the present example the planning controller has a very specialised role which is very closely connected to a successful flow of inbound and outbound traffic. For this reason, the position of planning controller should be considered carefully in terms of knowledge and experience. The results of this study also highlighted the reliance on technology and the reduced opportunities for human communication; most of the transfer of information in the new system is via the FPS screen and flight data label, which has implications of trust in both the machines and people as there is less transparency in data transfer.

Finally, the evidence from this study highlights the potential vulnerability of the perception and vigilance system. The new electronic display takes much opportunity away to realise discrepancies in the flight data displayed; this is something in the paper FPS system which was very robust as it was self generated and not just monitored. Lastly the lack of personalised manipulation and annotation of the FPS in the new system has an impact on the memory system, particularly the factor of ‘to–be-remembered’ data (prospective memory) and the issues associated with remembering to transfer information within the team.

It was also clear that in the new system the radar controllers needed complete trust in the data they received and that the reliance on the planning controller was reduced to monitoring their inputs, rather than communication via voice or gesture as seen in the paper FPS system.

The last comment regarding the work is associated with the interpretation of the tables. It has already been highlighted that this study was an example and that choosing different systems to analyse will necessarily change the outcome. However, it should be stated that whatever the findings in the risk analyses, those interested in HERA-PREDICT should also carefully analyse the tables associated with the error, their mechanisms and Contextual Conditions. The data concerned with these issues (Tables 7 and 8) need careful discussion, preferably with a team of subject matter experts, (controllers, human factors specialists, and safety experts), to better analyse and understand the individual contributions to the system, rather than just an outcome of overall risk.

Finally, it should be noted that, as with most other methodologies, training is recommended to better familiarise those using this technique.

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ABBREVIATIONS AND ACRONYMS

For the purposes of this document, the following abbreviations and acronyms shall apply:

a/c	aircraft
ATC	Air Traffic Control
ATCO	Air Traffic Controller / Air Traffic Control Officer *(US/UK)*
ATHEANA	A Technique for Human Event Analysis
ATM	Air Traffic Management
CAHR	Connectionism Assessment of Human Reliability
CCs	Contextual Conditions
CREAM	Cognitive Reliability and Error Analysis Method
DAS	Directorate ATM Strategies *(EUROCONTROL Headquarters, SD)*
DAS/HUM *or just* HUM	Human Factors Management Business Division *(EUROCONTROL Headquarters, SD, DAS)*
DNV	Det Norske Veritas *(UK)*
EATM(P)	European Air Traffic Management (Programme)
EDD	Electronic Data Display
EM	Error Mechanism
ET	Error Type
ETA	Estimated Time Arrival
E/V	Error/Violation (type)
FPS	Flight Progress Strip
FTA	Functional Task Analysis
HEP	Human Error Probability
HERA (Project)	Human Error in ATM (Project) *(EATM(P), HRS, HSP)*

HFFG	Human Factors Focus Group *(EATM, HRT; formerly known as 'HFSG')*
HFSG	Human Factors Sub-Group *(EATMP, HRT, today known as 'HFFG')*
HMI	Human-Machine Interface
HRA	Human Reliability Assessment
HRS	Human Resources Programme *(EATM(P))*
HRT	Human Resources Team *(EATM(P))*
HSP	Human Factors Sub-Programme *(EATM(P), HRS)*
IANS	Institute of Air Navigation Services *(EUROCONTROL, Luxembourg)*
IP	Information Processing level
LVNL	Luchtverkeersleiding Nederland *(ATC The Netherlands)*
PC	Planning Controller
PSG	Programme Steering Group *(EATM(P), HRS)*
RC	Radar Controller
REP	Report *(EATM(P))*
SID	Standard Instrument Departure
TID	Touch Input Device
TMA	Terminal Manoeuvring Area
WP	Work Package

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APPENDIX: HERA-JANUS TAXONOMIES

The use of the relevant HERA-JANUS taxonomies/tables to identify the errors and their mechanisms and the Contextual Conditions[14].

1. Error Details

Can the controller miss information - mishear / mis-see / not detect / detect late?

YES ☐ **Go to Perception and Vigilance**

Can the controller forget information – stored information / recent information/future actions?

YES ☐ **Go to Memory**

Can the controller misjudge information – error in planning / problem-solving / decision-making?

YES ☐ **Go to Planning and Decision-making**

Can the controller make an action error – performing physical action / speech

YES ☐ **Go to Response Execution**

[14] Note that the use of italics and colour codes throughout the tables is to assist those making decisions about the most frequent and severe issues. Data from many incident investigation activities within Europe have suggested the most prevalent and severe issues associated with the ATM system. These are coded as follows: black italics indicates a low level of prevalence and/or severity, blue indicates a medium level of prevalence and/or severity, and red a high level of prevalence and/or severity.
Obviously, as feedback from experience in incident investigation from each Country, Centre or Unit is shared with the safety management groups, additions and changes can be made to these highlighted items which better reflect the local situations.

2. Error Mechanism and Information Processing levels

Information Missed – Perception and Vigilance Errors

Can the controller….?	**Can the controller….?**
Hear incorrect/weak/obscured information ☐ - Go to Contextual Conditions	Fail to detect information after visual search ☐ - *Visual search failure*
Detect but mishear auditory information ☐ - No detection	Fail to monitor people/information/ automation ☐ - *Monitoring failure*
Mishear/confuse auditory information ☐ - *Misheard*	Have a strong expectation /mindset about the information ☐ - *Expectation bias*
Recognise auditory information too late ☐ **-** *Late auditory recognition*	Wrongly associate incoming information with something else ☐ - Association bias
Have a pilot read back of instruction ☐ - *Hearback*	Confuse separately but closely displayed information ☐ - *Information confusion - spatial*
Mis-identify/confuse visual information ☐ - *Mis-identification*	See information which sounded/looked like others ☐ - Information confusion- visual/auditory
Misread information ☐ - *Misreading*	See information which was not identified because of size/brightness/loudness ☐ - Discrimination problem
Mis-perceive information ☐ - Mis-perception	See information which was on the edge of display ☐ - Out of sight bias
Fail to make a visual search ☐ - Visual search failure	Fixate/tunnel on prominent information ☐ - Tunnelling
Fail to detect or detect late visual information ☐ - *No/late visual detection*	Have too much information or work with ☐ - *Information overload*
Fail to identify or identify late visual information ☐ - *No/late visual identification*	Have too little information or work with ☐ - Vigilance problem
	Have a momentary distraction or long-term preoccupation ☐ -*Distraction/preoccupation*

Information Forgotten – Memory Errors

Can the controller….?	**Can the controller….?**
Forget to monitor a/c ☐ - *Forget to monitor*	Forget/lose awareness of equipment mode ☐ - Equipment mode error
Forget to perform action ☐ - *Forget planned action*	Get confused because of similar information ☐ - *Similarity of information*
Perform an action too late ☐ - *Forget to perform action*	Have too much information to work with ☐ - *Memory capacity overload*
Forget already carried out action ☐ - *Forget previous action*	Have a distraction or preoccupation during work ☐ - *Distraction/Preoccupation*
Forget information in working memory ☐ - *No/inaccurate recall of temporary information*	Feel that stored information interfered with recalled information ☐ - Negative transfer of information
Have inaccurate recall of stored information ☐ - Mis-recall of information in long-term memory	Feel that the information was stored incorrectly or not learned properly ☐ - Mis-stored/not learned information
Have no recall of stored information ☐ - *No recall of information in long-term memory*	Consider the information was rarely used ☐ - Rarely used information

Information Misjudged – Planning and Decision-making

Can the controller….?	**Can the controller….?**
Misjudge the projection (time/ space) of a/c ☐ - *Misjudge a/c projection*	Have incorrect / mis-stored knowledge ☐ - *Incorrect knowledge*
Make an incorrect decision/plan for a/c ☐ - *Incorrect decision/plan*	Have lack of knowledge ☐ - *Lack of knowledge*
Make a late decision/plan for a/c ☐ - *Late decision/plan*	Fail to consider side effects and future situation ☐ - *Prospective memory failure*
Make no decision/plan ☐ - *No decision/plan*	Misunderstand a received communication ☐ - misunderstand communication
Make an insufficient plan for a/c ☐ - *Insufficient plan*	Fail to integrate information ☐ - *Information integration failure*
	Fixate on a specific plan ☐ - *Fixation*
	Wrongly assume information ☐ - *Incorrect assumption*
	Fail to prioritise high importance tasks ☐ - *Incorrect priority of task*
	Fail to convey the danger involved because of pride/overconfidence ☐ - Denial of risk
	Fail to convey the danger involved for others reasons ☐ - *Failed to recognise risk*

Action Error – Response Execution

Can the controller….?	**Can the controller….?**
Make an error in typing ☐ - Typing error	Perform an action due to strong habit ☐ - Problem of habit
Make an error in selecting an object ☐ - *Selection error*	Confuse objects to be selected ☐ - *Spatial confusion*
Make an error in positioning an object ☐ - Positioning error	Incorrectly perform action because it was too precise ☐ - Lack of manual precision
Mis-time an action/communication ☐ - Timing error	Confuse the look of the object ☐ - Problem of similar look
Transmit or record indistinct information ☐ - *Unclear information transmitted/recorded*	Deliver a message with pauses/stammers/ mumbling ☐ - *Unclear speech*
Transmit or record incorrect or inaccurate information ☐ - *Incorrect information transmitted/recorded*	Deliver a message with inappropriate tone ☐ - Wrong voice tone
Fail to transmit/record information ☐ - *Information not transmitted/recorded*	Deliver an incorrect instruction in relation to turn/heading ☐ - Spatial confusion
Fail to carry out other actions ☐ - *Omission of action*	Perform an action due to a 'triggering' thought ☐ - *Intrusion of thought*
	Perform an action or speech whilst being interrupted ☐ - *Interruption from environment*
	Perform an action or speech which was unintended ☐ - *Slip of the pen/tongue*

3. Contextual Conditions

Can there be Pilot-Controller Communication issues?		**Can there be Pilot Actions?**	
Pilot language/accent difficulties	☐	*Responding to TCAS Alert*	☐
Similar confusable call signs	☐	*Response time to ATC instructions*	☐
Pilot read back incorrect	☐	*Correct pilot read back followed by incorrect action*	☐
Pilot experience	☐	Rate of turn	☐
Situation not conveyed by pilots – urgency/party-line support	☐	Rate of climb/descent	☐
ATC or pilot breach of R/T standards/ phraseology	☐	Other – State	
Speech tone/rate	☐		
Complexity of ATC transmission	☐		
Pilot high/excessive R/T workload	☐		
ATC high/excessive R/T workload	☐		
A/C stuck transmitter	☐		
R/T interference	☐		
R/T cross-transmission	☐		
R/T blocked frequency	☐		
Other – State			

Can there be Traffic and Airspace issues?		Can there be Weather issues?	
Sector capacity limitations	☐	Snow/ice/slush	☐
Excessive traffic load	☐	*Fog/low cloud*	☐
Complex traffic mix	☐	Thunderstorm	☐
Fluctuating traffic load with unexpected demands – off route traffic	☐	Extreme winds at high altitude	☐
Holding patters	☐	Extreme surface winds	☐
Underload	☐	Other - State	
Post peak traffic	☐		
Unusual situation – emergency or high risk	☐		
Flight in non-controlled and controlled airspace	☐		
IFR/VFR mix	☐		
Flight in transitional airspace	☐		
Airspace design characteristics – complexity, changes	☐		
Traffic management initiatives	☐		
Temporary sector activities	☐		
Other - State			

Can there be Documentation and Procedures issues?			
Orders	☐	*Unclear*	☐
Charts/notices	☐	Contradictory	☐
Temporary notices	☐	*Ambiguous*	☐
Advisory manuals	☐	Incomplete	☐
Checklists	☐	*Inaccurate*	☐
Automated references	☐	Too complex	☐
Special information	☐	*New/recent changes*	☐
Other-State		*Not available*	☐
		Other – State	

Can there be Training and Experience issues?	
Knowledge for position	☐
Experience on position	☐
Time on position	☐
Unfamiliar task in routine operations	☐
Novel situation	☐
Over-training	☐
Mentoring	☐
On the job training	☐
Emergency training	☐
Team resource management	☐
Recurrent/continuation training	☐
Controller under training	☐
Controller under examination/check	☐
Other – State	

Can there be Workplace Design and HMI issues?				Environment issues?	
Working position/ console, e.g. HMI	☐	*Conflicting information*	☐	*Noise from people*	☐
Surveillance, e.g. radar	☐	*Failed/broken equipment*	☐	Noise from equipment	☐
Communication, e.g. radio	☐	False information	☐	*Distraction/ Interruption*	☐
Navigation, e.g. approach aids	☐	*Feedback problem*	☐		
Flight information display, e.g. FPS and display	☐	High false alarm rate	☐	Air quality	☐
Auxiliary equipment, e.g. generators	☐	Illegible information	☐	Lighting problems	☐
		Inaccessible information	☐		
Other information display, e.g. weather	☐	*Incorrect information*	☐	Pollution/fumes	☐
		Interference	☐	Radiation	☐
Equipment warning devices, e.g. alarms/alerts	☐	Lack of equipment/information	☐	Other - State	
Other - State		Lack of coverage/range	☐		
		Lack of precision	☐		
		Lost information	☐		
		Mode confusion	☐		
		No equipment/information	☐		
		Nuisance information	☐		
		Poor design	☐		
		Poor display	☐		
		Poor positioning	☐		
		Recently introduced equipment/information	☐		
		Equipment size problem	☐		
		Suppressed information	☐		
		Unavailable equipment/ information	☐		
		Unclear equipment/information	☐		
		Unreliable equipment/information	☐		
		Untrustworthy equipment/information	☐		
		Visibility of equipment/information	☐		
		Other – State			

Can there be Personal Factor issues?		**Can there be Team Factors issues?**	
Fatigued	☐	*Adequate assistance from controllers*	☐
High anxiety/panic	☐	*A problem with controllers using unclear working methods*	☐
Suffering from boredom	☐	*A problem with supervisors cooperating with staffing and traffic flow*	☐
Suffering from complacency	☐	A problem of personnel – flight data/ maintenance supporting operations	☐
Suffering from lack of confidence	☐	*A problem of management support*	☐
Other- State		A problem of cooperation amongst supervisors	☐
		A problem of cooperation amongst management	☐
		Other –State	