Improving the mastery of human factors in a safety critical ATM organisation

– ANNA-MARIA TEPERI –

Cognitive Science, Institute of Behavioural Sciences,
Faculty of Behavioural Sciences, University of Helsinki, Finland

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Academic dissertation to be publicly discussed, by due permission of the Faculty of Behavioural Sciences at the University of Helsinki in Auditorium XII, Main Building, Unioninkatu 34, Helsinki, on the 7th of June 2012, at 12 o'clock.

Supervisors:
Professor ***Anneli Leppänen***
Finnish Institute of Occupational Health
Work Organizations
Finland

Research Professor ***Leena Norros***
Technical Research Centre of Finland
Automation and Human-Technology Interaction
Finland

Reviewers:
Dr ***Christine Owen***
Faculty of Education
University of Tasmania
Project Leader: Organising for Effective Incident Management
Bushfire CRC
Australia

Professor ***Matti Vartiainen***
Aalto University School of Science
Work Psychology and Leadership
Department of Industrial Engineering and Management
Finland

Opponent:
Professor ***Pascale Carayon***
Department of Industrial and Systems Engineering
University of Wisconsin-Madison
USA

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Abstract

A mastery of human factors (HF) in such complex systems as air traffic management (ATM) and air traffic control (ATC)[1] is crucial to maintain the efficiency and safety of the system and the well being of those working within it (Vicente, 1999; Kirwan, 2002; Reason, 2008; Carayon, 2010). ATC aims at preventing collisions between aircrafts. In ATC work, several characteristics cause complexity, uncertainty and dynamicity, and there is a possibility of risks and disturbances that make ATC vulnerable to human error. The discipline of HF applies knowledge regarding human behaviour to the design of systems (IEA, 2000; FAA, 2005). In the current thesis, HF is used as a tool for improving work, competence and safety in the context of ATM.

In the four studies on which this thesis is based, the application of HF to one ATM organisation was studied over a period of 10 years, and, in this process, the factors that supported or hindered the adoption and application of new thinking and new tools were evaluated. Interviews, intervention results, questionnaires and incident data were used as the material and methods for the studies. It was recognised that the organisation was run in strict compliance with international regulations and that it had a strong technical competence, but this was not the case with respect to HF aspects (Study I). The interviews of the upper and middle managers of the target organisation revealed that there was no unified strategy within the organisation for applying knowledge regarding HF (Study II). The results showed limitations in utilising incidents as material for organisational learning and safety improvement (Study III). Finally, the organisation succeeded in applying an easy-to-use tool to determine, analyse and learn about HF risks and resources (Study IV).

Taken together, the studies in this thesis demonstrated that, although there were cultural and structural barriers, such as a strong, fragmented and authoritarian history of aviation administration, that hindered the adaptation of new thinking, the HF application was facilitated by the tensions for change in which HF-based interventions and tools were considered valuable solutions. The current thesis indicates that the target ATM organisation should continue HF application to strengthen its competence as a high reliability organisation. In this future process, recognising the facilitating and hindering factors involved in the mastery of HF is necessary. The findings of this thesis also support the possibility of using HF application in other complex systems.

1 Conceptions of ATC and ATM and their relations to each other are defined in more detail in Figure 1, Section 1.2.

Tiivistelmä

Inhimillisten tekijöiden (Human Factors, HF) hallinta turvallisuuskriittisissä järjestelmissä, kuten lennonvarmistuksessa ja lennonjohdossa on välttämätöntä, jotta varmistetaan toiminnan sujuvuus, turvallisuus ja hyvinvointi. Lennonjohdon tehtävä on ehkäistä lentokoneiden yhteentörmäykset ja huolehtia lentoliikenteen sujumisesta turvallisella ja taloudellisella tavalla. Lennonjohtotyö sisältää monimutkaisuutta, epävarmuutta ja muuttuvuutta, jotka lisäävät inhimillisten virheiden riskiä. Inhimillisten tekijöiden tieteenala soveltaa käyttäytymistieteellistä osaamista järjestelmien toiminnassa. Tässä väitöskirjassa inhimillisten tekijöiden tietämystä käytetään lennonvarmistuksen työn, työn hallinnan ja turvallisuuden kehittämisen työkaluna.

Väitöskirja koostuu neljästä osatutkimuksesta, jotka kuvaavat inhimillisten tekijöiden soveltamista lennonvarmistusorganisaatiossa 10 vuoden aikana. Väitöskirjassa tarkastellaan sovellusprosessia heikentäviä ja tukevia tekijöitä, ja arvioidaan, miten uudenlainen ajattelu- ja toimintatapa omaksutaan organisaatiossa.

Tutkimuksissa havaittiin, että lennonvarmistusorganisaatio edustaa teknis-autoritaarista ympäristöä, joka hallitsee infrastruktuurin kehittämisen ja jonka toimintaa vahvasti ohjaa kansainvälinen normisto. Ihmisen toimintaa koskevaa osaamista on lennonvarmistuksessa sovellettu heikosti (Tutkimus I). Organisaation esimiesten haastattelut toivat esille, että inhimillisten tekijöiden tietämyksen hyödyntämiselle organisaatiossa ei ollut olemassa yhtenäistä strategiaa (Tutkimus II). Organisaation oppimisjärjestelmässä oli puutteita, mm. poikkeamien tietoja ei analysoitu systemaattisesti toiminnan tai turvallisuuden kehittämiseksi (Tutkimus III). Operatiiviseen toimintaan liittyviä inhimillisiä riskejä ja onnistumisia opittiin kuitenkin analysoimaan työn arkeen suunnitellulla työkalulla (Tutkimus IV).

Tutkimusten tulokset osoittavat, että kulttuuriset ja rakenteelliset esteet, kuten hajanainen ja vanhakantainen ilmailuhallinnon historia hidastivat inhimillisten tekijöiden osaamisen juurruttamista. Aihealueen hyväksymistä organisaatiossa kuitenkin edistivät toimintaympäristön muutostarpeet, joihin käyttäytymistieteellisten työkalujen ja lähestymistapojen ajateltiin tarjoavan uusia ratkaisumalleja. Lennonvarmistusorganisaation kannattaa jatkaa inhimillisten tekijöiden tietämyksen hyödyntämistä, kuitenkin tunnistaen sen soveltamista heikentävät ja tukevat tekijät. Tulokset voivat tukea vastaavaa työtä myös muissa turvallisuuskriittisissä organisaatioissa.

Acknowledgements

For me, this research meant 10 years of action research with more or less chaotic cycles of learning. I hope that this thesis will serve as a form of feedback and learning also for the target ATM organisation and the whole organisation (Finavia Corporation) under study. Although this thesis had an organisational scope, I hope that the described HF application served the organisation members and teams as well. Thank you all for the good times I had with you!

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The support and interest of both the operative personnel and the management of the Finavia airports and units are, for me, an experience that I will never forget. You helped me learn much about air navigation services and the work at airports – and patiently participated in the HF interventions and processes that were conducted at Finavia. Without you, this thesis would not exist. You did not lose your confidence in me even though I moved slightly from the role of face-to-face practitioner to investigator and researcher.

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My beloved family, Pietari, Emma and Kaisa: you had real patience throughout the numerous years of my commitment to this project – without having any choice. Unlike many other academic projects in general, this writing process gave us more time to spend time together. Still, I understand that my thoughts have been absorbed in this PhD activity, and you had to face the same joys, but also disappointments that were related with this academic effort. My precious husband, Pietari, you offered me practical, mental and intellectual support during the entire process.

List of original publications

This thesis is based on the following publications, which are referred to by Roman numerals I–IV in the text.

I **Teperi, A-M.**, Leppänen, A., 2011. From crisis to development – analysis of air traffic control work processes, Applied Ergonomics, Volume 42, Issue 3, March 2011, Pages 426–436. doi:10.1016/j.apergo.2010.08.019

II **Teperi, A.-M.**, Leppänen, A., 2011. Managers' conceptions regarding human factors in air traffic management and in airport operations. Safety Science, Volume 49, Issue 3, pages 438–449. doi:10.1016/j.ssci.2010.10.009

III **Teperi, A.-M.**, Leppänen, A., 2010. Learning at air navigation services after initial training. Journal of Workplace Learning, Volume 22, Issue 6, pages 335–359. doi: 10.1108/13665621011063469

IV **Teperi, A-M.**, Leppänen, A., Norros, L. 2011–1012. Application of new human factors tool in an air traffic management organisation. Submitted to Aviation Psychology and Applied Human Factors, revised in April, July and September 2011.

Abbreviations

ACC	Area control centre or area control
ATC	Air traffic control
ATCO	Air traffic controller
AFIS	Aeronautical flight information services
ANS	Air navigation services
ATM	Air traffic management
ATS	Air traffic service
CAA	Civil Aviation Administration
COORS	Confidential occurrence reporting system
CRM	Crew resource management
DCU framework	dynamicity (D), complexity (C) and uncertainty (U)
EASA	European Aviation Safety Agency
Eurocontrol	European Organization for the Safety of Air Navigation
FAA	Federal Aviation Administration
FCAA	Finnish Civil Aviation Administration
HFACS	Human factors analysis and classification system
HF	Human factors
HFE	Human factors ergonomics or human factors engineering
HRD	Human resources development
HSE	Health and Safety Executive in the United Kingdom
ICAO	International Civil Aviation Organization
IEA	International Ergonomics Association
IAEA	International Atomic Energy Agency
JAA	Joint Aviation Authority
NTSB	National Transportation Safety Board
OD	Organizational development
SES	Single European Sky
SHEL	A human factor model (including components Software,
SMS	Safety Management System
UK	United Kingdom
US	United States
VOR	VHF omnidirectional radio range

Figures used in this thesis

Figure 1. The aviation system and its components (ANS, ATS, ATM, ATC), according to ICAO, 2001, doc 4444.

Figure 2. International/global, European and Finnish ATM as a system.

Figure 3. Organisation chart of a typical Finnish airport

Figure 4. Timeline of Finnish ATM history – development of traffic, technology, tools and work.

Figure 5. The reality of the target ATM organisation (and the whole organisation as an overall context of it), the frameworks/approaches that could be utilised to improve and evaluate the mastery of HF in the target ATM organisation and the four main level of essential human-related factors in ATM

Figure 6. Timeline of the application of HF in the target ATM organisation and the phases of the data collection for the current thesis.

Figure 7. The HF tool.

Figure 8. The development phases of the target ATM organisation regarding the mastery of HF.

1. Introduction

1. Introduction

Aviation safety has been a major concern since the start of aviation history. Human error remains a contributor to even 80% of commercial airplane hull-loss accidents, making human factors (HF) the final frontier in improving aviation safety (Wiegmann & Shappell, 2003). During the last few decades, various international regulatory bodies have developed several requirements and guidelines regarding HF (e.g. NTSB, 2007; Eurocontrol, 2008; ICAO, 2009), and scientists have invented several tools, methods, concepts and theories with which to better master human risks (Hopkin, 1995; Stanton, Salmon, Walker et al., 2005; Hollnagel, Woods & Leveson, 2006; Reason, 2008).

Aviation systems are comprised of several components, of which air traffic management (ATM), a dynamic, integrated management of air traffic and airspace, is one. One part of ATM is air traffic control (ATC), which aims at preventing collisions between aircraft (see in detail in Figure 1). ATM and ATC are characterised by several complex, uncertain and dynamic characteristics, with a possibility of risks and disturbances (Woods, 1988; Vicente, 1999) that make it vulnerable to human error.

An awareness of HF in such complex systems as ATM is crucial in order to maintain the efficiency and safety of the system and the well being of those working within it (Vicente, 1999; Kirwan, 2001 a, b; Reason, 2008).

Currently the application of HF knowledge and tools can also be regarded as an innovation in safety critical environments (Carayon, 2010). As a discipline, HF aims at applying knowledge regarding human behaviour (e.g. human capabilities and limitations) in the design of systems (Wilson, 2000; FAA, 2005). In this doctoral thesis, the abbreviation HF represents both the field of study known as "human factors" and the properties of individual or social behaviour that are specific to a human's influence on the functioning of systems (i.e. "human factors"). One theoretical approach of this thesis is sociotechnical, including aspects of system and cognitive ergonomics, as well as learning and knowledge creation at work and in organisations. In addition, earlier research findings concerning HF in ATM have been used. ATM is regarded as a complex sociotechnical system, and the tools used during the HF application process have several aspects of a sociotechnical approach (e.g. Study I).

The author filled two roles in the target ATM organisation: 1) as an expert in human resources development (HRD) since 2000 and 2) as a HF expert from 2003 to 2010. The thesis explores the hindrances and successes of HF application in the target ATM organisation over a period of 10 years (2000–2010). The data of the thesis were collected in 2000–2010 with interviews, interventions, questionnaires (including qualitative and quantitative material) and incident report data.

The thesis is based on four studies focusing on the development of ATC work processes as a sociotechnical system after an air traffic controllers' (ATCOs') strike (Study I), the concepts regarding the HF adapted for the organisation by managers (Study II), the improvement in learning in ATM work from the HF aspect (Study III) and the application of a HF tool (which represents a sociotechnical approach) in the analysis of ATC work (Study IV).

The thesis begins with a presentation of ATM as a part of the aviation system, and Finnish ATM (including its historical phases) as the context of the studies on which this thesis is based. The theoretical background is then presented, including, at first, the definition and development phases of the field known as HF and the relevance of HF as a key safety factor in ATM systems. Frameworks of learning at work and in organisations are used, and their value as implications in this thesis is pondered. The implementation of HF as a new way of thinking and acting (as an innovation) in the target ATM organisation is then presented. Then, a few essential frameworks concerning the safety critical and sociotechnical nature of ATM are presented. The overall theoretical background of this thesis is summarised with a figure. The background is followed by the specific aims of the studies (I–IV) and the methods used in the thesis. Thereafter, each study is introduced and discussed. Finally the results are set in the more general context of the theoretical background of this thesis, and the factors that encouraged and hindered the mastery of HF are evaluated. Practices for improving HF mastery in the target ATM organisation (as well as in other safety critical domains) in the future are considered.

1.1 The context – the historical development of aviation

The role of HF in aviation has its roots in the earliest days of aviation. Already the first flights in the beginning of the 1900s indicated the paradox of aviation safety: the purpose of aviation was an adventure and discovery, but the flights had to be restricted in order to maintain safety (e.g. departure and destination locations had to be carefully selected). Instrumentation emerged for aircrafts during World War I and further improved in World War II (Koonce, 1999). The essence of the ergonomics was recognised especially by British aviation in its attempts to improve the ergonomics of the cockpits in military aircraft (Murrell, 1976).

Aviation is still expanding. More people need or want to fly, the number and types of aircrafts are increasing, and technical innovations are constantly being introduced in the control of aircrafts and in the human roles and jobs in aviation. In addition, the domain of HF as a discipline is expanding, producing new applications and topics to be employed (Garland, Wise & Hopkin, 1999).

1.2 Air traffic management as a system

Air navigation services (ANS) are provided for air traffic during all phases of operations. ANS include the following six categories of facilities and services: communication, navigation and surveillance services, meteorological services for air navigation, aeronautical information services, search and rescue, and ATM (ICAO, 2009).

ATM is defined as the dynamic, integrated management of air traffic and airspace – safely, economically and efficiently – in collaboration with all parties (ICAO, 2005). Its components are air traffic services, airspace management and air traffic flow management (ICAO, 2001, doc 4444, 1–3). ATM is comprised of several components, for example, airspace users (organisations operating aircraft and their pilots), airspace organisation and management, demand/capacity balancing, traffic synchronisation, and aerodrome operations (the needed ground infrastructure including, e.g., lighting, taxiways, runways) (ICAO 2005, 2–3). The ATM system has firm collaboration with supporting industries, such as equipment manufacturers, research and development organisations, and states and countries. The ATM system provides information to, or may receive information from, several partners, such as accident/incident investigation authorities, law enforcement (including police) and regulatory authorities. As an airspace owner, each state or country serves as an airspace provider that is responsible for addressing and resolving issues such as airspace sovereignty, national security requirements and collaborative ATM, thus ensuring that the airspace is organised and managed for the safety and efficiency of service (ICAO, 2005).

The generic term “air traffic services” (ATS) covers flight information service, alerting service, air traffic advisory service and air traffic control (ATC) service. ATC aims to prevent collisions between aircraft and maintain an orderly flow of air traffic through communication between pilots and ATCOs (Nolan, 1999; ICAO, 2001). ATC provides area, approach and aerodrome control services.

The concepts of ANS, ATM, ATS and ATC and their relations to each other can be seen in Figure 1.

***Figure 1*. The aviation system and its components (ANS, ATS, ATM, ATC), according to ICAO, 2001, doc 4444.**

In this thesis, mainly two concepts, ATM and ATC, are used to describe the kind of research activities that were conducted. With ATM, the whole system is referred to as a context of this study, and ATC refers to a special professional group and work as the object of study.

1.2.1 Global and European ATM

ATM is a global system that includes several geographically separate areas (e.g. Asia, America, Europe), as well as national levels or subsystems within these areas (Figure 2).

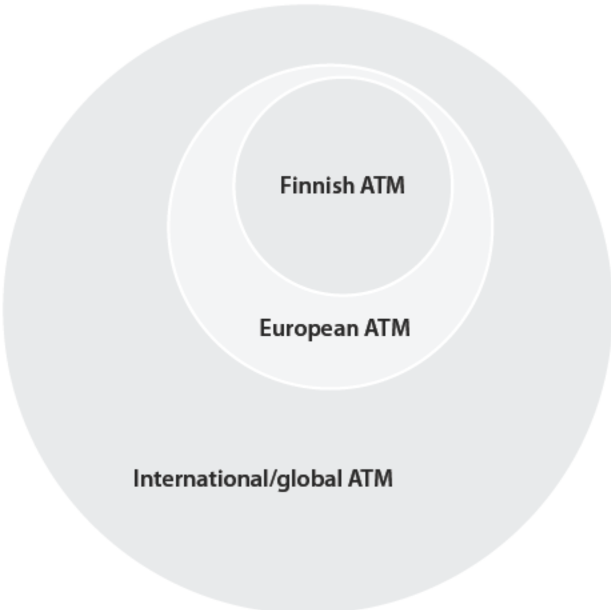

Figure 2. **International/global, European and Finnish ATM as a system.**

The aviation system is strictly guided and regulated internationally. Aviation safety regulation has several bodies, which are presented briefly in the text that follows. The International Civil Aviation Organisation (ICAO) was created in 1944 to promote the safe and orderly development of civil aviation worldwide. It is a specialised agency of the United Nations, and it develops international air transport standards and regulations and serves as the medium for co-operation in all fields of civil aviation among its 190 members (ICAO, 2010).

Other bodies dealing with aviation safety regulation are the European Commission, the national aviation authorities and the European Aviation Safety Agency (EASA). From 2003 on, EASA has attempted to create transnational aviation safety rules, and it, for example, monitors the implementation of standards through inspections in member states at the European level. It binds the participating 31 states and works hand-in-hand with the national authorities (EASA, 2009); this job was earlier dealt with by the Joint Aviation Authority (JAA) (Hakola, 2007).

The European Organization for the Safety of Air Navigation, Eurocontrol, founded in 1960, is an intergovernmental organisation made up of 39 member states, and the European

Community. It aims at improving the current European ATM system and developing its next generation. The Eurocontrol agency develops and co-ordinates the implementation of pan-European ATM programmes, operates a central flow management unit that keeps delays to a minimum and works closely with the member states, ANS providers and several other stakeholders[2]. Finland joined Eurocontrol in 2001 and, by doing so, became part of the European ATM system (Hakola, 2007).

ICAO (2005) has issued a vision for a global ATM operational concept "to achieve an interoperable global ATM system, for all users during all phases of the flight, that meets agreed levels of safety, provides for optimum economic operations, is environmentally sustainable and meets national security requirements" by 2025. As a part of this global vision, Eurocontrol has launched a long-term vision and strategy to build a "Single European Sky" (SES) that will deliver joint European ATM performance in the future (Eurocontrol, 2010). It also aims at improving safety, cutting delays and lowering air navigation costs for European airspace (Hakola, 2007, 155; Eurocontrol, 2010). In any case, SES has also been criticised as being too long-term a process with, for example, risks related to several political interests (Learmount, 2004).

To fulfil the aforementioned system-wide goal and assure compliance with international guidelines and regulations at the national level, the local policies and practices of each provider of air navigation services are regularly audited by national regulators (Trafi, 2010).

1.2.2 Finnish Civil Aviation Administration

Throughout its history, the Finnish ATM has been a part of the Finnish Civil Aviation Administration (FCAA), which is responsible for the national services of ANS, airport operations and other affiliated services needed at airports.

In order to understand the prerequisites of organisational learning and change (in this thesis, improving mastery of HF in the target ATM organisation), it is essential to recognize the contextual factors, especially the history of the organisation itself (e.g. Owen, 1999; Engeström, 2000; 2004). This section describes the historical phases of the organisation of FCAA (later known as Finavia and Finavia Corporation). Thereafter historical phases of the ATM are described in detail. At the end of this section, some remarks are made about the role of HF during the developmental phases of the FCAA and Finnish ATM.

From its outset in 1918, after the civil war in Finland, the Finnish aviation administration was fragmented. The administration of civil aviation was the responsibility of the general staff (assisting military commander), and most functions of the technical administration were turned over to central authorities and boards, for example, the National Road and Civil Engineering Board (which looked after airfields), the Board of Post and Telecommunications (which was in charge of aviation communications), and the National Board of Meteorology (whose responsibility was aviation weather). (Hakola, 1997)

2 In 2010, the number of flights in Europe totalled over 9 million, for which EUR 7.4 billion was billed for air navigation charges (Eurocontrol, 2009; 2010).

In 1931, Finland acceded to the Paris Convention with respect to international aviation, and the government was able to participate in the planning of international transport. In Finland, the building of airports needed both state guidance and funds. In 1937, an "assistant junior secretary for aviation" (under the Ministry of Transport and Public Works) was appointed the task of acting as the country's proper aviation authority, responsible for all matters related to air safety (e.g. observing international flight regulations and granting operational licences). Ministry-appointed part-time inspectors, most of whom were engineers from the Armed Forces, carried out these activities.

In 1943, an administrative unit called the Aviation Office was formed within the Ministry of Transport and Public Works. Earlier, the possibility of combining the air company Aero O/Y and the national civil aviation administration into a single private company had also been studied, but then cancelled[3]. Air traffic growth in the 1950s centred around domestic flights, and in the 1960s the international arena became important. In 1963, the co-ordination between airspace use and air surveillance with the Air Force was clarified.

By the 1960s, the fragmented nature of aviation administration was attracting increasing attention from politicians and within the industry itself. It was even reported that the approach of the aviation administration was unnecessarily slow and complicated in individual cases. This was probably the first time that organisational factors were raised and were of interest from the functional point of view. In 1972, a civil aviation board and an authority subordinate to it were established, and the National Board of Civil Aviation (NBA) began work. Three of its administrative functions were airport maintenance and ANS (by the Airports Department), air safety (by the Flight Safety Department) and general management (by the Administrative Department) (Hakola, 1997). These same functions can be found in the organisation structure even today (Finavia, 2010; see also Figure 3).

The first signals of outer pressures and a need for change were seen in 1980's and 1990's. By 1987, air traffic congestion was putting international political pressure on aviation officials. The ANS Department was set up, which was comprised of ATC, communications, navigation and other ANS facilities (see Figure 1). By 1990, reform was needed to create business models for state-owned firms, and, in 1991, a new state enterprise, the Civil Aviation Administration (CAA), began operating. The privatisation meant increased financial independence and the responsibility for the new organisation. Rapid reforms, such as modernisation and rebuilding, were started, especially regarding terminals, and the focus was on satisfying customer requirements. The Flight Safety Authority was established to carry out official civil aviation duties. It was independent of CAA's business operations, even though it was still a part of CAA.

In the 2000s, rapid changes occurred in the outer functional environment of the whole organisation. Finland joined the European Union in 1995, and a more open flow of people and products became possible. The aviation markets also became more open because of

3 This kind of solution for organising aviation administration was made in the USSR in 1923.

the deregulation of the air companies. Winter traffic in northern Finland increased due to international Christmas charter flights to Lapland, a number of low-cost airlines entered the Finnish market, and international activities to integrate European airspace emerged. In 2006, the FCAA started applying the new State Enterprises Act, and its official aviation duties were transferred to the Finnish Civil Aviation Authority, a separate body. The business organisation adopted a new auxiliary business name, Finavia (Hakola, 2007).

In 2010, the Finavia Corporation (Finavia Oyj in Finnish) began trading, continuing the operations of the Civil Aviation Administration/Finavia as a service company owned fully by the State of Finland. The transformation into a company was considered a way to provide the organisation with new possibilities to maintain and develop the airports, to create connections with the rest of the world and to serve air travellers and airlines, as well as Finnish business and the military. Finavia's ownership is controlled by the Ministry of Transport and Communications (Finavia, 2010).

To summarise, the history of Finnish civil aviation from the 1910's to the 2000's concentrated, at first, on organising the administration. At later phases, infrastructure, services and the business of air traffic were focused on. HF had not been mentioned as a scope or tool of the overall improvements. However, the aim of implementing HF into ATM is not new; already 20 years earlier, ICAO offered guidelines and regulations concerning the basic concepts (ICAO, 1989), training needs (ICAO, 1991) and investigation principles (ICAO, 1993) with respect to HF.

Today, the Finavia Corporation has a networked structure, and it maintains 25 airports throughout the country, of which 18 are civilian, 4 have joint services for civil and military operations, and 3 are military. One area control centre is responsible for ANS services for the upper airspace in both northern and southern Finland (Hakola, 2007, 201).

Most of the Finnish airports are small, and traffic is relatively low in most of them (approximately 17 000 to 150 000 passengers per year at most airports, 2500–7900 landings per year at military airports). The seven biggest airports had from 153 000 to 847 000 passengers per year, mainly commercial traffic, including winter charter flights. The airport with the highest traffic serviced 12 million passengers in 2006 (Hakola, 2007). Nationally, the company has a monopoly, and there have been no competitors. Recently, the challenge to develop a strong status as a hub for international traffic, especially Asian and European traffic, has risen (Finavia, 2010).

Despite its latest reformulations, the whole organisation has been reasonably stable, especially from the 1930s to the 1980s, without any strong inner or outer pressures on the airport structures or functions. In addition, the ATM provides a relatively stable work environment, and only since the 1990s has there been any pressure to improve ATC technology (e.g. Palukka, 2003, 164). It has also been found that a research approach that focuses on HF in high reliability environments was practically non-existent in Finland in the early 1980s, primarily because (as in many other countries) the aviation industry did not provide any significant incentives for tackling HF issues in its design or operations (Norros, 2004, 4).

The management of the whole organisation/company is organised in a matrix form in which the airports/units have economic and functional independence on one hand, but are committed to meeting the strategic goals of the business operations of the headquarters on the other. The business operations have been divided into the following business areas: ATM/ATC, airport operations (often including security) and, since 2006, also commercial business. Every airport has its own administration. For the whole organisation, other functions (e.g. public relations, safety and quality) support the main business areas; these functions are handled by the head office (Finavia, 2010).

The typical structure of a small or middle-size Finnish airport is presented in Figure 3.

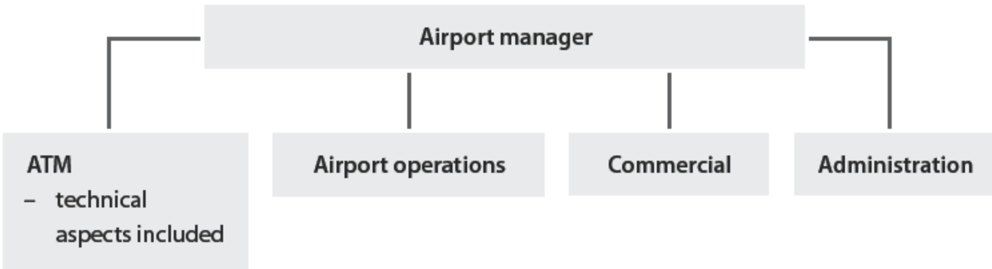

***Figure 3.* Organisation chart of a typical Finnish airport today.**

The work of ATM is described in detail in Section 1.2. Here, airport operations are described in more detail, because they are included as a one research scope in Study II. Airport operations maintain the airport infrastructure, including, in particular, ensuring adequate conditions in the manoeuvring areas (runways, taxiways). The conditions are determined by such factors as braking action, friction coefficient, and surface contamination. The conditions are reported (via ATM/ANS) to pilots to assure safe operations during taxiing, take-off and landing. Airport operations personnel have multiple tasks and also handle other activities at the airport, such as security and infrastructure maintenance. Baggage handling, refuelling, de-icing, passenger access and boarding are primarily handled by other partners (e.g. ground handling companies working at the airports; not mentioned at Figure 3).

1.2.3 Finnish ATM

As a part of the whole organisation (FCAA/Finavia), ATM had its own development phases (responses/solutions to the overall development of aviation business), mainly due to the technical improvement of aircrafts, as well as the quantity and speed of traffic. These cornerstones are presented in detail in Figure 4. (by Hakola, 1997).

1930s	1950s	1960s	1970s	1990–2000s
Preliminary ATC system created. Pilots broadcasted their position to radiostations from where it was relayed by telephone to ATC. Horizontal maps and drawing boards used to represent air traffic situation. Earlier, flights relied on flight instruments only, causing the risk of collisions.	A process board with flight strips taken into use. Each strip represented an aircraft, which could be placed in chronological or altitude order. First VHF radio telephones by which aircrafts could contact ATC. With the first radar, ATCOs were provided with a constant picture of air traffic. Non-directional radio beacons for route navigation.	Jet age started; increased use of upper airspace. International traffic increased. Air navigation systems and approach and landing aids developed rapidly. More accurate (VOR) beacons with distance measuring equipment gave the position of the aircraft in terms of direction and distance from the navigation ground station.	Adoption of secondary surveillance radar and related automatic flight data processing systems. ATCO could see a representation of air traffic, including aircraft radio calls, altitude, and speed on a radar screen.	Updating of the Finnish ANS system and standardising of ATM systems, e.g. including modernisations of equipment and the buildings of big units and an electronic system replacing communication with telephones between ATC units. Centalised regulation of European traffic loads started. Introduction of a new ATC system to adopt strip-free ATC operations at area control centres.

Figure 4. **Timeline of Finnish ATM history – development of traffic, technology, tools and work.**

The issues related to the historical development of the whole organisation, as well as the ATM and the impacts of this background on the organisational culture, are discussed later in the Discussion.

1.3 HF within the ATM

1.3.1 Definition of and research related to HF

According to the International Ergonomics Association (Wilson, 2000), HF (or synonymously ergonomics, sometimes also abbreviated as HFE) is the scientific discipline concerned with understanding interactions among humans and other elements of a system. The profession, human factors engineering, applies theory, principles, data, and other methods to design in order to optimise human well being and overall system performance. The Health and Safety Executive (HSE) in the United Kingdom (UK) has defined HF as the environmental, organisational and job factors combined with the human and individual characteristics that influence behaviour at work in a way that can affect health and safety (HSE, 1999).

Within the Federal Aviation Administration (FAA) in the United States (US), HF is defined as a multidisciplinary effort to generate and compile information about human capabilities and limitations, as well as to apply that information to equipment, systems, facilities, procedures, jobs, environments, training, staffing, and personnel management for safe, comfortable, and effective human performance (FAA, 2005).

A core principle of HF is systems thinking: HF professionals consider the network of interactions between individuals and various elements of their environment (or work system) (Wilson, 2000). The knowledge required to design, implement and disseminate HF is diverse. It relies on knowledge of basic scientific disciplines, such as physiology, sociology and psychology, as well as on knowledge of such applied sciences as industrial engineering, business and management (Carayon, 2010).

Several approaches and phases (or ages) of the analysis of HF and safety have been identified (Hale & Hovden, 1998; Sheridan, 2008; Reiman & Oedewald, 2009). However, they are not so clear and straightforward, as some views that have been hailed as modern have been around for some time in aviation (e.g. Wiener, 1977; 1980). The first age of the scientific study of safety (from the 19th century to World War II) concerned technical measures and represented traditional error/risk analysis. The person was usually considered the weakest component of the safety system (Heinrich et al., 1980). During this period, personnel training and selection were developed as preventive measures.

The second age of safety (from World War II to the 1970s) focused more on human error and human recovery, for example, as according to Rasmussen (1982). The limits of technical risk assessment and preventive measures were realised in the 1980s.

The third age of safety (in the 1990s) focused on safety management systems and organisational factor research, as well as on their development, with more pro-active aspects. The model of human error and organisational accidents developed by James Reason became widely accepted. This classification of unsafe acts distinguished between active and latent failures, the effects of which may lie dormant until triggered later by other mitigating factors. Different layers of the system infrastructure (defences or safeguards) ensure system safety and prevent the effects of failures (Reason, 1990; 1997). The Reason model has been criticised for making complex reality too linear and for remaining too abstract (Hollnagel, 2004).

The fourth era of safety science and HF (the 2000s) has emphasised human activity in coping with unexpected events in complex, underspecified and unpredictable work environments with restricted resources, the focus being on the strengths and capabilities of human operators coping with such work environments and resources. This pro-active approach to safety management is called resilience engineering. Resilience engineering stresses the need to comprehend mechanisms and create capabilities in organisations, via which they continuously anticipate, recognise and adapt to disturbances and surprises in their environment (e.g. Hollnagel, 2004; Hollnagel et al., 2006; Hollnagel, 2009). The 2000s have also stressed the need to learn from events and system-wide aspects (Leveson, 2011), as well as the need for continuous co-operation between regulators, service providers and companies to enhance joint cognitive systems (Hollnagel, 2003; Reason, 2008) – even including the organisational, geographic, cultural and temporal boundaries of the systems (Carayon, 2006). In the 2000s, organisational and safety culture (formed by shared values, norms and perceptions within the organisation) has been focused on (e.g. Schein, 1992; Hopkins, 2006; Weick & Sutcliffe, 2001; 2007). In addition, the concept of human and organisational factors (HOF) has been used in the literature and in research. In this thesis, however, the concept of HF is also considered to include organisational factors because, in any case, organisational factors are formed by human actions and behaviour.

1.3.2 HF in ATM – guidelines and earlier research

The implementation of HF has been a global aim in aviation, and HF has been widely recognised as critical to aviation safety and effectiveness. According to international safety regulatory bodies (FAA, 2005; ICAO, 2005), long-term improvements in aviation safety will come primarily from HF solutions. According to these bodies, consistent, long-term support for HF research, development and analysis, as well as for the application of HF information, should be established, because humans will play an essential role in the global ATM system over the next few decades. Humans manage the system and monitor its performance to ensure the desired system outcome.

Demands to meet HF challenges have also been made in Europe, for example, in several Eurocontrol safety regulatory requirements (e.g. Eurocontrol, 2002) and publications regarding occurrence analysis (Eurocontrol, 2005) and training specifications (Eurocontrol, 2008).

Scientific research regarding HF in ATM has been active, but mainly only regarding its individual and work aspects, especially highlighting the cognitive capabilities, work demands and personal traits or psychophysiology of ATCOs (Vogt, Adolph, Ayan et al., 2002; Palukka, 2003; Koskela & Palukka, 2010). However, studies on organisational, collective, social and co-operative characteristics have been rare (Isaac & Ruitenberg, 1999; Batteau, 2002; Palukka, 2003; Koskela & Palukka, 2010; Chang & Yeh, 2010), even though they have been recognised as notable safety factors since the 1990s (e.g. Weick & Roberts, 1993; Reason, 1997; Perrow, 2007, 291).

Next, earlier research is presented in more detail in regard to individual, work, group and organisational aspects. Several researchers have identified the existence of these four levels or parts of safety critical systems (Wickens, 1991; Vicente, 1997; 1999; Roske-Hofstrand & Murphy, 1998; Kirwan, 2002).

Several ATC accident investigations concerning *individual controllers* have highlighted such individual limitations as attention slips and errors in judgement as causes of accidents (Danaher, 1980; Billings & Reynard, 1984). This approach is nowadays considered too simplistic for the analysis of work in complex sociotechnical systems (e.g. Dekker, 2002; 2007), but it still sometimes emerges. For example, the final accident report on the air crash in which the Polish president was killed (Final Report, 2011) placed most of the blame for the accident on the pilots. Focusing on individual features creates the risk of stating criminal responsibility in such cases (Dekker, 2007).

Another concept that has been used to explain controller performance (usually limitations) is vigilance (the ability of an observer to maintain attention over long, uninterrupted periods). The ability to detect critical signals drops rapidly, inducing a slowing of reaction time or an increase in error rate during task monitoring (e.g. Tattersall, 1998). In addition, the effects of fatigue on operators' performance (e.g. lowered attention, higher risk taking, increased error rate) have been a concern (Costa, 1995; Tattersall, 1998), as has their contribution to ATC-related aviation mishaps (NTSB, 2007). Stress may arise in ATCOs due to a feeling of a loss of control, fear related to the consequences of errors, relations with supervisors and colleagues or other incidents (e.g. Costa, 1995; Tattersall, 1998; Vogt et al., 2002). Means for coping with stress, for instance, in cases of critical incidents in ATC (Vogt et al., 2002; Leonhardt & Vogt, 2006), have been conceived and recommended.

In order to analyse operator performance in ATC cases, some useful terms have been introduced and used in academic studies or investigations. The concept of the situational awareness of the operator has been used, meaning the person's perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future (Endsley, 1995; Endsley & Smolensky, 1998, 130). It has also been recognised that, in order to cope with work demands, ATCOs need an accurate mental model, an internal presentation of the system that they are dealing with (Norman, 1986; Schorrock & Isaac, 2010), so that they can predict, explain and understand the environment and interaction around it. For ATCOs, a specific mental model may be situation specific (e.g. a certain type of traffic) or it may represent the entire task domain (e.g. the entire flight sector or operating guidelines) (Garland et al., 1999, 263; 479).

From the aspect of *work characteristics* (e.g. type of equipment, workload), especially the increasing level of automation in ATC has been actively studied by several researchers (e.g. Tattersall, 1998; Kirwan, 2001a, b; Metzger & Parasuraman, 2003; 2005). These researchers have reported that automation in ATC is necessary because of the need for more efficient traffic flow or the need to compensate for human vulnerabilities (e.g. the move towards free flight and pilot-mediated ATC), but questions arise about the adequate risks related to human control over automated systems, mistrust of automation and complacency or underload. The effects of automation on ATC were especially studied in the United States in the late 1990s (e.g. Wickens, Mavor & McGee, 1997), but the topic is still current today because of the future visions of ATC automation and systems that still raise concerns about facilitating human centred automation (e.g. Kirwan, 2001a, b; 2002; Vogt et al, 2002). And today, the ATC system has been found to suffer disruptions as a result of the limitations and reliability of equipment such as radar systems, radiotelephone quality or equipment layout. In European ATM studies, degraded modes have been found to occur when operators struggle to maintain levels of service, even though key elements of their infrastructure have failed (Johnson, Kirwan & Licu, 2009).

The mental workload experienced by ATCOs has also been an active topic of research. In such studies (e.g. on the impact of airspace complexity, the number of aircrafts under control, potential conflicts between aircrafts, time pressure and unforeseeable events concerning workload), the estimations of operators have been studied (e.g. Rantanen & Nunes, 2005; Hilburn & Flynn, 2005; Rantanen, Naseri & Neogi, 2007; Yang, Rantanen & Zhang, 2010). The effects of underload caused by an insufficient workload or automation have also been studied, the results indicating that underload can cause boredom, complacency and degraded conflict detection (Danaher, 1980; Metzger & Parasuraman, 2005).

ATC relies on the performance and skills of *groups and teams* rather than on the performance of individuals; for example, mutual performance monitoring is needed (Cox & Sharples, 2007; Koskela & Palukka, 2010). The social aspects of ATC work have to be taken into account when training needs are being assessed (Oprins et al., 2006; Koskela & Palukka, 2010; Malakis, Kontogiannis & Kirwan, 2010) and attempts are being made to maintain system safety (Rognin & Blanquart, 2001). In the study of 51 ATC teams, Smith-Jentsch et al. (2009) found that the teammates with greater experience working together accepted back up from one another better than did those with less experience working together. In some serious aviation mishaps with ATC input, power status or situational constraints have inhibited fluent information exchange and the correction of unclear communication among the crew (e.g. Weick, 1993; Agenzia Nationale Per la sicurezza del volo, 2004). A study by Eurocontrol (2004) analysed a total of 444 ATM incidents related to air–ground communication between controllers and pilots in 2002–2003. The most frequent risks were found to be the loss of communication or the use of non-standard phraseology by operators in communication (Eurocontrol, 2004)

There has been a notable development of co-operative and non-technical skills in the implementation of training in crew resource management (CRM) in aviation (Murray, 2009), as well as in other high-risk areas (Salas, Bowers & Edens, 2001; Flin, O'Connor & Mearns, 2002). This work has enhanced learning and promoted the desired behavioural changes in both ATC (Murray, 2009) and several other safety-critical domains (Salas et al., 2001). Although CRM education is included in ATC training guidelines (Eurocontrol, 2002), it has not yet been efficiently implemented in ATC (Salas & Cannon-Bowers, 2001; Owen, 2004; Schroeder, Bailey et al, 2006; Koskela & Palukka, 2010). Furthermore, the most empirical team studies have focused on military command and aircrews rather than on the teams working in ATC (Salas, Prince et al., 1995). Isaac & Ruitenberg (1999, 186) have stated that it is typical for ATC environments to have strong, even negative stereotypes about other units or teams with whom they co-operate. Strong subcultures have been recognised also in the context of Finnish ATM (Hanski, 2002; Palukka, 2003).

Organisational structures, conflicts and cultures have been found to constrain opportunities for learning and improving the ways of acting in ATC (Owen, 1999; 2009) and other complex systems (Salas & Cannon-Bowers, 2001; Weick & Sutcliffe, 2003). Participative planning (Wilson & Russell, 2003) and a positive organisational climate have supported change management in ATC (Arvidsson, Johansson et al., 2006), and it has been concluded that organisational features play a more significant role than individual differences or peer relations in how ATCOs interact with their environment or ATC systems (Chang & Yeh, 2010). Concerns have been raised regarding the fact that, while safety levels improve, organisations make decisions in which safety records are further optimised, usually due to economic goals (Ek, Akselsson et al., 2007; Johnson & Kilner, 2010 concerning ATC; Amalberti, 2001; Perrow, 2007 concerning several high reliability domains).

ATC is one part of the aviation system (ICAO, 2001; 2005; Hollnagel, 2003) (see also Figure 1), which is comprised of several components. Co-operation between different organisations is needed to assure success in one of the ATC basic demands, that of managing a complex mixture of air traffic from commercial, general, corporate, and military aviation (Wickens et al., 1997). Currently, the vast majority of ATM risks are caused by general aviation, non-commercial pleasure flights that infringe on controlled airspace, mainly due to navigation failure and non-adherence to the use procedures established for the involved airspace (Eurocontrol, 2007). This situation indicates that, from the systemic learning point of view, challenges still exist with respect to improving ATC. For several years already, the system viewpoint has been recognised as a necessary aspect of organisational development studies (e.g. Hakkarainen et al., 2003; Engeström, 2004).

1.4 Learning at work and in an organisation

The basic aim of this thesis is to describe how the ATM organisation learned to master HF and how the mastery of HF improved in 10 years. Mastery is defined as comprehensive knowledge of, or skill in, a subject, but also as the process or action of mastering a subject (Senge, 1990; Webster's dictionary, 1996).

Currently work-related knowledge, organisational learning and knowledge management are regarded as prerequisites for organisational success (Leppänen, Hopsu et al., 2008). Organisations are becoming more knowledge intensive, and there are new ways in which work organisation and information technology are changing work (Boland & Tenkasi, 1995; Boreham, 2002). These are also the features that the ATM embodies internationally (Owen, 1999; Metzger & Parasuraman 2005; Murray, 2009) in Europe (Eurocontrol, 2002; 2004) and in Finland nowadays (Koskela & Palukka, 2010). The pressure to adapt in the transformations in worklife and to successfully realise planned organisational changes (e.g. Hendry, 1996; Robbins, 1996) requires that organisations become more aware of the issues of knowledge and learning.

In dynamic and unpredictable work environments, such as ATC (e.g. Kirwan et al., 2001; Vogt et al., 2002), the role of the work community in the creation of work process knowledge has been emphasised (Weick & Roberts, 1993; Owen, 1999; Boreham, 2002). Communities-of-practice have been regarded as critical in developing learning organisations (e.g. Hendry, 1996). Within communities-of-practice, people share tacit knowledge and, through dialogue, bring it to the surface; they exchange ideas about work practices and experiment with new methods and ideas. In discussions, the theories in use are affirmed or modified, new problem-solving routines are adopted, and the social context is managed and repaired (Hendry, 1996). However, learning from mere experience may also limit responses and strategic options and develop learned incompetence (Hendry, 1996; Leppänen, 2001; Ahonen & Virkkunen, 2003; Leppänen et al., 2008) or hazardous ways of acting (Billett, 1999), which may threaten possibilities to offer safety services for ATM or other complex systems.

In organisations, the support of learning requires that the work content be challenging, the organisation of the work be characterised by autonomy and participation, and the leadership activities include features of coaching (e.g. Oliveira et al., 2002; Leppänen et al., 2008). These are characteristics that have also been regarded as prerequisites for the creation of learning organisations.

One approach for studying and developing work processes is based on the theory of cultural historical activity. It regards work as a socially distributed activity system in which changes in the system elements cause contradictions or disturbances in other elements of the activity system. For example, if the object of the activity changes, it can affect the tools (instruments, concepts) used by the workers, and with which they try to reach the goals or aims of the work process. The workers have different roles, or there is a division of labour that is also affected by changes in the other elements of the activity system. It has been assumed that the real development of a work process requires an analysis of the historical development of the work activity and the elements of the work process and the contradictions between them (Engeström, 2000; 2004). Contradiction, disturbances or incoherence within activity systems provides a potential driving force for change (Blackler, 1995; Engeström, 2000). This approach offers a valuable framework with which to recognize some remarkable changes and contradictions in the history of Finnish aviation and ATM. For instance, from the 1930's to the 1990's, the object of ATM activity changed due to the technical improvement of aircrafts, as well as changes in the quantity and speed of traffic. These changes forced the equipment and work distribution to be renewed (see Sections 1.2.2. and 1.2.3 and Figure 4. for historical details).

The work processes can and should be developed both by and with the workers (Virkkunen, 1995; Norros, 1996). It has been shown, for instance, that workers (especially novices) learn a lot during the joint process of externalising, analysing and correcting knowledge regarding the work process. It has been proven that observing and participating in the open handling of errors, open dialogue, and empowerment initiatives that increase the information of system faults increase the job knowledge and competence of employees (e.g. Leppänen, 2001).

A conscious analysis of work is necessary to meet the complex, dynamic and uncertain situations that exist in risk prone environments, such as ATM (e.g. Roske-Hofstrand & Murphy, 1998; Kirwan et al, 2001; Vogt et al., 2002). Analytical orientation is a key factor also in the handling of normal operations (Norros, 2004; Eurocontrol, 2007; Norros & Nuutinen, 2009). Reflection on disturbances is not always possible (Rogalski et al., 2002) because of the workload, communication breakdowns or other vulnerabilities found in ATM (Wickens, 1999; Durso & Manning, 2008; Chang & Yeh, 2010). Work is often done in shifts, and only a few professionals have the opportunity to learn from experience in a new or rare situation. Contextual and cultural vulnerability was also recognised in ATM, when Owen (1999; 2009) found that, in ATC on-the-job training, some workplace instructors actively rejected principles typically associated with adult learning. Therefore, interventions to enhance the creation of work process knowledge are needed (Leppänen, 2001). At the same time, perceiving the facts, or determining how such action can be put into practice in safety critical organizations, must be evaluated. There have, however, been relatively few such interventions and evaluations.

There have also been only a few studies carried out on the processes or outcomes of development that have been led by an internal facilitator or coach, although the process of adopting habits of acting that support learning and participation in work development is only starting in organisations (Leppänen et al., 2008). To the best knowledge of the author of this thesis, no long-term studies have thus far been carried out on the application of HF in ATM organisations from the viewpoint of the adoption of new thinking, while the scientific focus has been on the cognitive work demands of the individual operator (e.g. Batteau, 2002; Koskela & Palukka, 2010), and the descriptions of HF applications in ATM have concerned more short-term HF interventions with single HF issues, for example, training in ATC (Oprins et al, 2006; Murray, 2009).

1.4.1 Learning a new way of thinking and a method supporting it

Aviation has often been among the first industries to apply new technologies, and, thus, also among the first to encounter and resolve the HF issues associated with them (Garland et al. 1999). In any case, in Finnish aviation, HF issues had not been raised proactively, even though professional discussion and research concerning HF was proceeding at the international level (e.g. Wiener, 1977, 1980; ICAO 1989, 1993). In this way, implementing HF in Finnish ATM can be defined as an innovation in which a novel set of behaviours, routines and ways of working are directed towards improving, for example, production outcomes or the user's experience and which is implemented by planned and coordinated actions (Greenhalgh, Robert, Macfarlane et al., 2004). What then helps the organisation to apply and implement a new way of thinking (HF) and acting (HF tools)? And what hinders this process?

In ergonomics, several researchers have pondered the challenges to be met when putting new methods or tools into practice (Broberg, 1997; Kirwan, 2000; Kerr, Knott et al, 2008; Zink, Steimle & Schroeder, 2008). Findings for HF programmes or applications in ATM are few or lacking.

In this section, the aspect of innovation is mainly used to illustrate the potential challenges related to HF applications because this type of work was recently been carried out in the safety critical field of health care (Carayon, 2010, using Greenhalgh et al., 2004), and the findings seem to be of relevance to the ATC environment. In this model, HF is expressed as an innovation whose diffusion, dissemination, implementation and sustainability need to be understood and specified in order for it to be applied efficiently. Diffusion is the passive spread of innovations and changes, whereas dissemination involves active and planned efforts to convince target groups to adopt an innovation. The implementation of the innovation includes active and planned efforts to incorporate an innovation within an organisation. An innovation is sustained if it is institutionalised and routinely used within an organisation (Greenhalgh et al., 2004). In addition, due to environmental pressures, changes must be put into practice in organisations in order to survive (e.g. Robbins, 1996; Schein, 1996; Hendry, 1996; Perrow, 2007).

This thesis describes a change process that can be more explicit only after its facilitating and hindering factors have been recognised.

1.4.2 Value of a new way of thought and a tool (HF) for implementing it

Carayon (2010) and Kirwan (2003) have stated that HF is more likely to be adopted by organisations if clear advantages in terms of effectiveness or cost-effectiveness can be demonstrated. In addition, innovations that are compatible with the adopter's values, norms and needs are more likely to be adopted (Greenhalgh et al., 2004).

Furthermore, the implementation and diffusion of HF is more likely to be accepted by workers if HF intervention or a HF programme has been shown to improve task performance and if workers can directly experience the benefits of the implemented activities, for example, if work processes are redesigned by the removal of performance obstacles or if conflicts among different professional groups are solved (Kirwan, 2003; Carayon, 2010).

HF tools and methods represent varying levels of complexity (Carayon, 2010), and, in ATM, some methods have been recognised as being too complicated or too time-consuming to be used (e.g. Wiegmann & Shappell, 2003), or the methods represent the object of the analysis in a too narrow, even misleading scope (Dekker, 2002). Thus HF professionals need to devise creative ways of applying HF to a system in order to show its value to the organisation (e.g. they need to consider the workload of operative professionals and create new approaches that do not add to the already high workload of professionals).

Carayon (2010) has provided recommendations that help HF experts, researchers and educators succeed in applying this new method (see also Kirwan, 2000; 2003, HF programmes in the nuclear industry and process industries). Firstly, HF experts should be perceived as credible. Therefore, they need to have much experience in the domain in which they are working so that they understand its operative environment. In addition, they should have strong interpersonal skills that will help them learn about the domain and listen to its operators, but also skills to help them facilitate communication between HF experts.

HF experts, researchers and educators need to co-operate and form networks that provide added value to the organisation. For instance, HF professionals involved in safety work can help

HF researchers to identify significant research issues, and HF educators need to understand the needs of HF professionals and researchers in order to develop effective training and educational programmes. HF experts should also be knowledgeable about the HF innovation itself, as well as being knowledgeable about the process used to implement the innovation, in order to be an effective change agent. In particular, communication with top management should be coached by HF experts (Carayon, 2010; also Robbins, 1996).

Carayon (2010) has recommended, for instance, that HF researchers develop and test simple, reliable and valid HF tools and methods, and also develop models and theories about mechanisms between work system characteristics and other HF variables and safety. HF students should also be taught to be change agents in organisations. The dissemination of HF in organisations could rely on a network of HF-trained operators who are spread throughout the organisation and available to work on specific projects (Robbins, 1996; Carayon, 2010). In a "train-the-trainer" model, HF experts transfer their knowledge and expertise to a small group of selected employees. Over time, this group of employees gains HF knowledge and experience, and the role of the HF experts becomes a supporting one (Carayon, 2010).

1.4.3 Organisational features that affect learning

In general, in organisations, the following four types of barriers to the creation of safety systems have been identified: strategic barriers (e.g. unclear responsibility for safety across organisations), cultural barriers (e.g. autonomy of professional groups that may hinder effective teamwork), structural barriers (e.g. improvement at the department or unit level versus improvement at the system level) and technical barriers (e.g. a lack of evidence about what works) (Carayon, 2010; also Leveson, 2011).

Strong leadership, strategic vision and a climate conducive to experimentation and risk are characteristics of organisations that are receptive to change (Senge, 1990; Greenhalgh et al., 2004). The implementation of HF innovations can be particularly challenging, however, if organisations tend to have strong professional boundaries and professionals tend to function within mono-disciplinary communities (Carayon, 2010)

An organisation is ready for HF innovations if there is tension for change and HF is considered a promising solution to current problems. If there is pressure on an organisation to improve quality and safety, it creates an environment more receptive to change. Nevertheless, information needs to be provided to leaders and top managers so that they understand the (potential) benefits of HF in improving the safety culture (e.g. Flin, 2006); case studies and actual examples of safety projects could provide support in informing these benefits (Carayon, 2010).

Organisational readiness for innovation is also influenced by whether the impact of the HF effort has been assessed and is anticipated, whether there is support and advocacy for HF within the organisation, whether dedicated time and resources can be allocated to the HF effort, and whether there is a capacity, and a system in place, for evaluating the actual and anticipated effects of the HF effort. All of this activity requires significant preparation and planning to ensure that the organisation is ready for the HF (Kirwan, 2000; Carayon, 2010).

1.4.4 Environmental factors affecting learning in an organisation

Many external factors influence the adoption of innovations in organisations in general (e.g. Jokisaari & Vuori, 2010). Informal inter-organisational structures, quality improvement collaboratives, uncertainty in the wider environment, and political directives, as well as efforts aimed at spreading HF innovations in the surrounding industry, have all been found to be impacting factors (Greenhalgh et al., 2004; Carayon, 2010).

Organisations, especially those working in the safety critical domain, are closely intertwined with their surrounding society. Accidents and disasters, when happening in safety critical domains, not only reveal the failure of the organisations themselves, but also disclose the vulnerabilities of social structures and cultures, and the regulations and political systems around them (Amalberti, 2001; Perrow, 2007). In addition, accidents that happen in safety critical domains have an impact on their social and physical environment. For example, in the Fukushima catastrophe in Japan, the tsunami and the associated large amount of debris caused widespread destruction of many buildings, doors, roads, and other onsite infrastructures and also severely affected communication systems both inside and outside of the site (IAEA, 2011).

After severe risks or accidents, actions and pressure created by stakeholders or other parts of the system should focus the actions that are taken by a single organisation (Cook & Woods, 2006; Perrow, 2007). In aviation, therefore, stakeholders and co-operators (e.g. Ministry of Transport and Communications, airlines, the Air Force, authorities, international bodies, research and training institutes) should agree on the aims of applying and mastering the means and methods used in safety management, including HF (Amalberti, 2001; Hollnagel, 2003). Formal dissemination programmes of national and international organisations can facilitate the building of relationships between HF experts and operative organisations and policymakers (Greenhalgh et al., 2004).

1.5 Approaches adopted in studies of complex sociotechnical systems

ATM can be seen as a sociotechnical system that is composed of technical, psychological and social elements (Vicente, 1999). It can also be considered a *complex* sociotechnical system because it has several of the following dimensions: large problem space, social (composed of many people that work together) atmosphere, heterogeneous perspectives (workers' diverse set of disciplines), distribution, dynamics, a potentially high level of hazards, many coupled subsystems, automation, uncertain data, mediated interaction via computers and disturbance management (Vicente, 1999, 5–9, 11–17). The approach of using sociotechnical systems is one of the basic disciplines used in evaluating work systems (Vicente, 1999), as well as in applying HF in safety critical domains (Kirwan, 2000; Carayon, 2010).

Several characteristics create complexity, dynamicity, and uncertainty in ATC work, and it is assumed that all ATC operators have to cope with these work demands. The three dimensions of the DCU framework – dynamicity (D), complexity (C) and uncertainty (U) – were originally introduced by Woods (1988), and they were used by Norros (2004) to build a CDU model that included a proposal on how skills, knowledge and collaborative resources can be used to cope with work demands. According to earlier study findings, there are several factors that cause complexity in ATC systems, for instance, the number of interactions within the system or the combinations of traffic volume and traffic mix (Roske-Hofstrand & Murphy, 1998; Kirwan et al., 2001; Vogt et al., 2002; Hilburn & Flynn, 2005). The dynamicity of ATC is exposed in the state of the ATC system, which changes both autonomously and as a consequence of manipulation (Vogt et al., 2002; Manning & Stein, 2005; Cox et al., 2007). Uncertainty in ATC refers to, for example, multiple, ill-defined goals (e.g. efficiency and safety) that are in conflict (Ek et al., 2007; Atak & Kingma, 2011).

In addition to the sociotechnical approach, that of cognitive engineering is relevant, and it helps to understand the problem area of this thesis. The research approach of cognitive engineering aims at improving complex, sociotechnical systems such as work environments. It is an interdisciplinary approach to the development of principles, methods, tools and techniques that can be used to guide the design of computerised systems intended to support human performance (Roth, Patterson & Mumaw, 2001).

The goal of cognitive engineering is to develop systems that are easy to learn and use and that result in improved human–computer system performance. Poor use or a poor introduction of (new) technology can result in systems that are difficult to learn or use, can create an additional workload for system users, or, in the extreme, can result in systems that are more likely to lead to catastrophic errors. Thus work in complex safety critical domains should be modelled, designed or evaluated from the viewpoint of HF (Vicente, 1999; Roth et al., 2001), including also the joint cognitive and co-operative demands at the system level (meaning also clients and regulators), which should be evaluated and enhanced (Hollnagel, 2003).

1.6 Summary of the theoretical background of this thesis

This section presents the theoretical framework of this thesis, summarising various approaches and conceptions that have been used to identify the phenomenon of this thesis (improving the mastery of HF in a safety critical ATM organisation). The summary is illustrated in Figure 5, which has different elements. At first, the key premises, assumptions and elements underlying the theoretical framework of this thesis are described. The relationships of the various elements of the theoretical framework to each other are then discussed. Here, ideas of a framework by Crossan, Lane and White (1999) are referred to.

Before the mastery of HF can be realised, the conception and definition of the field known as HF must be clarified (see Section 1.3.1). ATM as a sociotechnical system (see Section 1.2.), as well as the reality of the target ATM organisation (e.g. the need to improve HF mastery, described in Study I, II) as the object of interventions/improvements, must be evaluated – including its history and other contextual factors, for which the sociocultural approach was used. In order to improve the mastery of HF in the target ATM organisation, conceptions and frameworks of learning at work and organisational learning were considered useful. A few other frameworks (cognitive engineering, CDU, see Section 1.5) were also considered important for a better understanding of the safety critical nature of the target ATM organisation.

Finally, the conception of innovation (see Sections 1.4.1, 1.4.2. and 5) was chosen as a valuable tool with which to evaluate the whole HF application process in the target ATM organisation.

Literature concerning HF in ATM and other complex, safety critical domains has revealed that interest must not only focus on the individual level, but should also include work characteristics and group and organizational factors (see Section 1.3.2), if the safety of services is to be maintained (also Crossan et al. 1999, 523). But these findings must be applied in a concrete way in order to be used in such a highly operative field as ATM – this kind of implementation is described in Study IV of this thesis.

The use of the different theoretical frameworks and approaches as a way of revealing the reality of the target ATM organisation is presented in Figure 5. In the figure, the overall reality of the ATM (and the whole organisation as an overall context of it) is presented as an outer main circle. Inside the main circle, theoretical frameworks and conceptions utilized in this thesis (and in Studies I–IV) are referred to; they were the background approaches that helped to improve – and also evaluate – the mastery of (HF) in the ATM organization. In the four smaller circles, the four main levels of HF in ATM are represented.

The figure also shows that not all of the reality of the whole organisation/ target ATM organisation can be caught by the frameworks, models or conceptions used in this thesis. The studies (I-IV) of this thesis try to explain how the used interventions could impact or improve the reality of ATM. In addition, the theoretical background of each study is presented in more detail at the original articles (in the appendix).

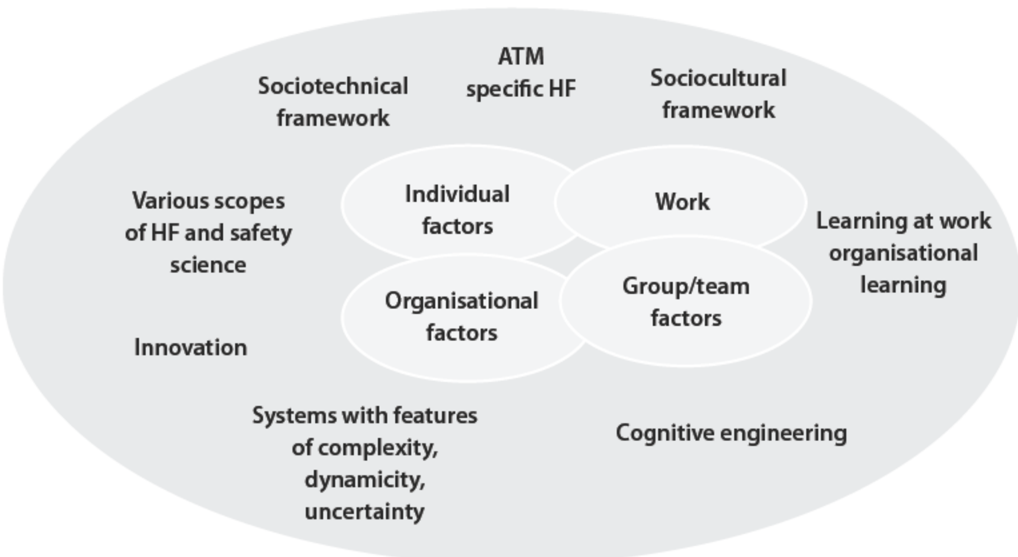

Figure 5. **The reality of the target ATM organisation (and the whole organisation as an overall context of it), the frameworks/approaches that could be utilised to improve and evaluate the mastery of HF in the target ATM organisation and the four main level of essential human-related factors in ATM.**

1.7 Applying HF in the target ATM organisation

Before 2000, there was no systematic application of HF in the organisation under study, but several actions had been taken. In 1985, the Finnish Institute of Occupational Health studied ATC job characteristics. The resulting review (by Johansson & Kalimo, 1985) made some recommendations for improvements in the work of ATCOs.

In the 1990s, a few severe ATC incidents called attention to the need to use external HF experts in investigations (AIB, 1993; 1994; 1997; 1999). In these investigations, core demands of the work, the risk proneness of work practices, unit management and work atmosphere in ATC were analysed. The reports stated, for example, that "there are deficiencies in the working practices particularly with regard to commitment to norms and common practices" (AIB, 1997, 46). In addition, differences were found in the views regarding unit management, and it was recommended that these be analysed and cleared up in open discussions because "internal management should create a co-operative and positive atmosphere that could facilitate carrying out the core tasks of ATC." (AIB, 1997, 53–54). On the basis of a thorough analysis of work practices (by AIB, 1993), the FCAA commented on the usefulness of considering that experts in behavioural sciences and work psychology also be used in forthcoming incident/accident commissions in order to maximise the value and objectivity with respect to the background factors of such incidents (AIB, 1993, commentary of FCAA on 2nd May 1997). The international audit by the UK civil aviation authority in 1998 revealed that, although the operation was safe and international standards were being met, there were problems with such organisational issues as leadership and the management system (ANS audit Finland, 1998).

Active trade union politics in the 1970's through the 1990's created a negative public image of ATCOs (Hanski, 2002). This negative image helped produce a need to study the construction of ATCOs' professional identity and the legitimisation of the profession's status in the labour market. This study was conducted by Palukka (2003), who started the research as an internal researcher, using group interviews and the cultural studies perspective.

A long-term HF application was started in the target ATM organisation of this study after the ATCOs' strike in 1999, when a high-level ANS group (composed of external and internal experts of the FCAA) made several proposals for improving the ANS work environment (Final Report, 1999). One result was the hiring of an HRD expert with a work and organisational psychologist background in 2000 (see Figure 5).

In 2003, the position of HF expert was formed in the safety and quality unit of the target ATM organisation. The former HRD expert continued in the role of HF expert. In the organisation, the reporting culture was becoming more open, and much incident data were available. It was also noted that causal factors behind the incidents were often related to human aspects (e.g. co-operation or communication problems) (Teperi, 2003). The HF expert started several activities, in particular HF training for ATC personnel. HF was also included in the reporting and investigation of ATC incidents, conducted by the safety and quality unit. These activities were described in the manual for the safety management system of the target ATM/whole organisation. In addition, an internal network of HF trainers (from

2008) was formed within the organisation to ensure the competence and commitment of the ATC operators.

As the roles of both the HRD and HF experts were new within the organisation, there was a need to both ensure the quality of the HF applications and also consider the process more deeply with the support of other experts, in favour of a scientific background. Thus, simultaneously with the practical HF application, data were collected, analysed and reported for the current thesis. Therefore, the author of this thesis had dual roles within the organisation, first as a practitioner and then as a researcher (the role of the author of this thesis as a HF expert/facilitator and, after that, as a HF researcher is pondered in the Discussion, see section 5.5). These roles and main activities in 2000–2010 are shown in Figure 6.

2000–2002	2003	2004–2007	2008	2009–2011
HRD expert position started. Actions and interventions from the work and organization psychology points of view.	HF expert position started. Need to use knowledge in psychology to improve aviation safety.	HF training for ATC personnel. Investigations with an HF contribution. Participation in national and international networks. HF activities started as teamwork.	HF network started; HF trainees coached by the HF expert. HF data collection from incident data started.	More-active communication with the top management regarding HF.
Study I started.		Study I follow up. Study II data collected. Study III data collected.	Study III data collected. Study IV data collection started.	Study I–IV reporting.

Figure 6. **Timeline of the application of HF in the target ATM organisation and the phases of the data collection for the current thesis.**

To summarise, within the ATM organisation, a need to better master HF had been raised, and several tools and concepts were introduced to create competence with regard to HF: analyses of ATC work processes (in 2000), the introduction of the HF concept (in 2003), the start of HF training for ATC operators (2004–2007), and the introduction of a new tool to analyse HF in ATC incidents (2008–2011), with the aim of activating ATC operators to consider their operative environment more carefully.

2.
Aims of the study

2 Aims of the study

The current thesis deals with the factors supporting and hindering the application of HF with respect to the target ATM organisation over a period of 10 years. HF has been regarded as a crucial area of competence with regard to the creation, maintenance and improvement of safety. In this thesis, HF is regarded as a new way to learn and improve work, competence and safety in the target ATM organisation.

The specific aims of the studies were

1) To evaluate the intervention on the basis of a work process analysis that was started in Finnish air traffic control (ATC) after a strike; the different actors' conceptions of the project aims, as well as the consequences and actual development needs of the ATC work, were evaluated (Study I)
2) To determine managers' conceptions of HF in air traffic management (ATM) and in airport operations (Study II)
3) To study the means used for individual, group and organisational learning in ATM work after an initial training period and to determine what practices need to be improved to enhance learning at work (Study III)
4) To evaluate the use of, and users' experiences with, the HF tool; the HF tool was used by ATC operators as a quick and easy-to-use tool for revealing the human-related causal factors of ATC incidents (Study IV)

3.
Materials and methods

3 Materials and methods

There was a need to use both qualitative and quantitative methods and data to answer the research questions of the studies. In the analysis of the data, aspects of between-method triangulation (Denzin & Lincoln, 2007) and mixed methods (Tashakkori & Creswell, 2007) were used. Qualitative data were used to examine human behaviour and the social, cultural, and political contexts within which it occurs (Salkind, 2009). Thus it was possible to obtain an abundance of material that reflected cultural issues of the object of the study, which would not have been possible with the use of quantitative methods only (Vicente, 1997). There was also a need to know more about the generality of some actions and conceptions (e.g. learning while working, in Study III) – for which quantitative data were more apt. Both types of data were used in an integrated way in the discussion and conclusions. It would not have been possible to draw comprehensive, meaningful conclusions with the use of a single method or one set of data only (Tashakkori & Creswell, 2007). The interpretation of the data collected via multiple methodologies is an essential component of any organisational diagnosis. An analysis of complex organisational systems demands a requisite variety in data collection methodologies in order to mirror the complexity that they attempt to describe (Paul, 1996).

The approach of naturalistic decision making (NDM) research was also realised in this thesis. NDM emerged in the 1980s as a means with which to study the decision-making process of people in real-world settings, especially in the kind of work settings that represent high-level goals, dynamic conditions and team coordination (Klein, 1998, 4). These kinds of features have been found to be relevant in ATM, too (e.g. Rantanen & Nunes, 2005; Rantanen et al., 2007). The NDM focus on field settings and its interest in complex conditions provides insights for HF practitioners into ways to improve work performance – also the goal of the HF application process introduced in this thesis.

There is a need for descriptive studies in order to reveal areas for future research (Vicente, 1997) and obtain an in-depth picture of the characteristics of existing phenomena.

3.1 Participants

The studies in which this thesis is based on include data from ATC personnel/ATCOs, ATC managers and airport managers (Studies I, II, III, IV) and AFIS (aeronautical flight information services) personnel and chiefs (Study III) working at Finnish airports. Experts and directors of head office departments (Study I) were also participants. Several members outside the organisation (from research centres, the Ministry of Transportation and Communication, an airline) also participated (Study I). Some of the intervention or other materials were gathered from process groups (Study I, ATCOs participating) and safety and quality groups of the airports (Study IV, ATC and airport managers participating).

The participating groups had varying roles at airports and in the ATM organisation: airport managers are responsible for airport activities in general, such as finance and community relations. The ATC managers were foremen of ATC units and were responsible for operational activities. They also participated in operative routines and worked in shifts, and also dealt with administrative work as well. The ATC personnel/ATCOs worked in operative duties (monitoring the movements of the aircrafts) and reported occurrences and incidents that took place during the operations (see also the airport organisation chart, Figure 4).

3.2 Interviews

Interviews were used in Studies I, II and III. In Study I, at the beginning of the intervention (in 2000-2001), different partners in (n=13) and out (n=3) of the ATM organisation were interviewed in order to determine the project goals. Interviews were also made after the intervention in 2005 (n=7, members of the ATM organisation). In Study II, ATC chiefs (n=12) and airport managers (n=9) were interviewed to determine their conceptions of HF. [There was no possibility to interview the chiefs or other participants in airport operations, but the airport managers were asked for their opinions of the theme, as they had thorough knowledge of the area.] In Study III in 2006, ATC chiefs (n=11) and airport managers (n=9) were interviewed to determine their conceptions of learning in ATC work.

In Studies II and III, interviews were conducted because of the need to determine the supervisors' conceptions of HF while the area was new in the organisation. The semi-structured interviews originally included 34 items, of which 12 had been used in Study II, and 4 items were selected as material for Study III. Similar themes had been used by researchers who had studied the prerequisites for a learning organisation in the Finnish paper industry in the 1990s (Leppänen et al., 1997). The questions had been shown to be valid then for the assessment of learning in different functional environments and were also considered suited for the scope of Study III.

The interviews took an average of 1 to 2 hours and were recorded.

3.3 Intervention material (development plans)

The intervention was evaluated in Study I. During the intervention (in 2000–2003), process groups in four ATC units (A–D) made plans regarding the most important development needs of their ATC work. The development plans were based on work process analysis models, which were the products of the intervention, but not used as research data of this study but instead served as background material for the development plans. A work analysis previously used in complex industrial processes (Leppänen,

2001) was implemented as a basis for the tool, but one item of the method ("analysis of raw materials in the production process") was excluded and replaced with an analysis of "information processing" to better describe the mental workload and conceptuality of ATC work. In the intervention, the following four aspects of ATC work were analysed: 1) the products and outcomes of the ATC work processes (e.g. communication with the aircrafts), 2) information processing and how information is used at work (e.g. skills, knowledge, information sources and equipment needed in ATC work), 3) the critical phases of ATC work (e.g. risky situations or disturbances) and 4) co-operation (within the work process and with related work processes).

The development needs were collated into a one sheet form (called the "development plan") including the following items: object to be developed/what has to be done, reasons for why this issue must be developed, proposals for practical actions, pros and cons for starting this development action, prerequisites for implementing the actions, the actors who make decisions concerning the proposal at hand, the responsible actors and the actual performer for the actions, and the timetable set up for the actions.

In ATC unit A, the process group (6 ATCOs) met for 10 days and produced work process models (I–IV) in table form and 64 development plans. In ATC unit B, the process group (3 ATCOs and 2 ATC assistants) met for 10 days, producing work process models (I–IV) in table form and 12 development plans plus extra tasks (e.g. survey of information flow within the unit). In ATC unit C, the process group (2 ATCOs, 1 ATC assistant) met for 7 days to form work process models (I–IV) in table form with some photos and maps from the workplace design and layout and 11 development plans. In ATC unit D, the process group (4 ATCOs and other ATC unit personnel) worked for 10 days to produce work process models (I–II) in table form and work process figures and flow charts, pictures of the work unit layout, and analytical text, including six development plans.

3.4 Open questions (in two questionnaires)

Open questions were used in Study III and Study IV. Three open questions of the reporting system questionnaire filled out in 2004 were used in Study III. The original reporting system questionnaire was an in-organisation survey that assessed developmental needs of the confidential observation and an occurrence reporting system in the organisation, including 27 quantitative questions and 7 qualitative open questions. Three selected open questions concerned learning from incidents and were as follows: "What have you learned from the occurrences or incidents you experienced during your work career?", "What are the main reasons for not reporting cases that should have been reported?", 'How should the reporting system be improved/developed?". Altogether 308 questionnaires were sent, and 155 were returned, the final response rate being 50%. The data from the open questions in this study were handled as qualitative data because the goal was to reveal the conceptions of the participants (Uljens, 1989).

In Study IV, the ATC operators' user experiences and the development needs of the HF tool and its use were studied using two open questions ("What experiences have you had with using the HF tool?" and "How would you improve the HF tool or its use?") in 2008 and 2009. These questions were included in the questionnaires filled out annually to complete the safety actions in each unit and were to be answered by the safety and quality groups of each ATC unit (only ATC managers were members of these groups). The users' experiences with the HF tool were elicited in 2008, and development needs were asked about in 2009. In both 2008 and 2009, 23 units responded to the questionnaires. Some units either did not complete their report on safety actions, or no data were available. In 2008, 17 units commented on the use of the HF tool, and, in 2009, all 23 units commented on it. In the open question data, some units had made brief comments (few words), and the more active units provided between one and two pages of text on their experience with the use of the HF tool.

3.5 Safety culture questionnaire

In Study III, selected items of the safety culture questionnaire were used. The survey was conducted in the organisation in 2008. The safety management system (SMS) had been started in the organisation at the beginning of 2006. The aim was to evaluate the workers' own responsibility and attitudes towards safety. The basis of the questionnaire was a safety culture questionnaire that was formulated by Eurocontrol with the help of the University of Aberdeen and has been used by several air navigation service providers around Europe (Eurocontrol/Mearns and Gordon, n.d.). Most of the questions were reformulated by the HF expert of the organisation (the author of the study) in co-ordination with a consultant who implemented the questionnaire. The reformulation of the questions was based on the knowledge collected over several years of HF training sessions, audits in the organisation and interviews concerning HF (interviews used in Study II). Local circumstances and the work culture were focused on.

The questionnaire originally consisted of 38 questions, and 11 of them were chosen for this study to assess themes of reporting and learning (such as "I can bring up my mistakes and errors). The items were rated with values from 1 to 7 (1= totally agree, 2 = somewhat agree, 3 = slightly agree, 4 = slightly disagree, 5 = somewhat disagree, 6 = totally disagree, 7 = do not know). There were originally 212 respondents from various professional groups from airports and units. Altogether 142 participants were chosen for this study. They were groups of ATC/AFIS personnel (n=102) and ATC/AFIS chiefs and airport managers (n=40) (no separate data from ATC chiefs and airport managers; instead they formed a common group).

3.6 HF tool

In study IV, an easy-to-use tool (the HF tool) was applied for gathering data on positive and negative HF-related causal factors in ATC incidents (Figure 7).

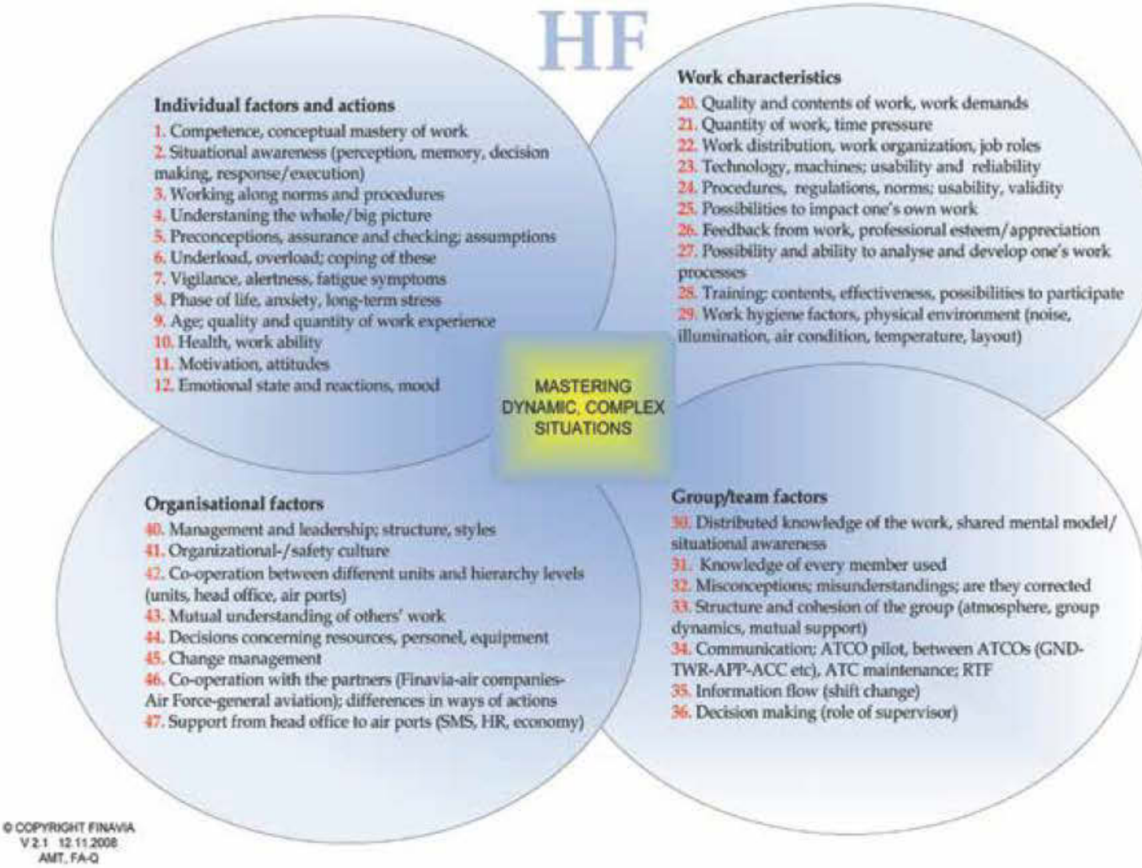

Figure 7. **The HF tool.**

The HF expert of the ATM organisation developed the HF tool in several phases during 2002–2009 (starting with a prototype designed in 2002; Runway Safety Report, 2002), and it was used as a part of the application of HF in the target ATM organisation (e.g. in safety and HF training sessions, incident investigations and safety audits).

The HF tool consisted of four parts (I–IV) that aimed at describing the individual (I), work (II), group (III) and organisational (IV) factors or characteristics that may contribute to the safety and efficiency of ATM operations or that can be causal factors of the incidents emerging at the ATM system. The method sees ATM as a sociotechnical system that is composed of psychological, technical and social elements (Vicente, 1999) (e.g. controllers, equipment and pilots as "external partners") that are in continuous relation with each other (Roske-Hofstrand & Murphy, 1998; Leveson, 2011).

The tool was based on literature on factors that affect safety. The bibliographic analysis of 1682 HF scientific papers in the *Human Factors* journal in 1970–2000 by Lee, Cassano-Pinche & Vicente (2005) also showed that the most frequently cited HF papers concern individual factors (e.g. the workload of the operator), work characteristics (e.g. skills training, displays supporting task performance) and group factors (e.g. interactive communication). Although organisational factors were not so frequently cited in the studies, they have more recently been the subject of active research and discussion (e.g. Dekker, 2002; Hollnagel et al., 2006; Perrow, 2007; Reason, 2008).

Each of the four parts of the HF tool consisted of items to be assessed, a total of 47 (see Figure 7). The items in Part I describe individual ATC operators' actions and their psychological states or characteristics, such as situational awareness (Endsley, 1995; Yang, Rantanen & Zhang, 2010), or stress (Costa, 1995) as sources of HF risks or strengths. The items in Part II describe work characteristics, for example, technology and systems (Norman, 1986; Johnson et al., 2009). Part III includes items describing group and team factors, for instance, communication among team members or the correction of misunderstandings (Weick, 1993; Salas et al., 2001). Items in Part IV refer to organisational factors, such as safety culture (Weick & Sutcliffe, 2003; Ek et al., 2007; Atak & Kingma, 2010).

The items of the HF tool try to describe the factors that can either facilitate or hinder ATC operators' work. Thus they are used to refer to the causal factors that contribute to incidents in both a positive (maintaining safety) and a negative (risking safety) manner. Including both positive and negative influences means recognising human behaviour variability, which includes both the strengths and the risks of the ATM system (Hollnagel et al., 2006). Some of the items in the HF tool were (positive or negative) causal factors, some were contributing factors, and others were contextual conditions. These were not conceptually separated in the design phase of the tool, nor during the application of the tool.

Training was given in the use of the HF tool before its implementation, and instructions on its use were included in the SMS manual of the organisation and placed on the intranet of the ATM organisation. The procedure for using the HF tool was as follows: ATC operators (managers, personnel) were asked to evaluate each incident report (that were sent to the reporting system) by marking the critical/suitable items of the case according to the HF tool. Not all of the 47 items were responded to; instead only the ones concerning critical causal factors of the incident at hand were chosen. Both the positive (maintaining safety) and negative (risking safety) causal factors were marked according to the HF tool.

In the study, a total of 3163 ATC incident[4] reports were assessed with the HF tool in 27 ATC units during 2008–2010. The ATC managers assessed 2716 of them, and ATC personnel were responsible for 447. Altogether 8782 HF-related positive and negative causal

4 The conception of an incident as one form of risk: A hierachical variety of conceptions, risks, occurrences, incidents, accidents, catastrophies/crises can be used to describe the level of severity, the costs and the effects to people and material (e.g. Amalberti & Wioland, 1997).

(or contributing) factors of the incidents were identified, of which 6790 causal factors were noted by ATC managers and 1992 were recorded by ATC personnel. Each incident report/case usually included multiple causal factors, and reports could be assessed by both ATC managers and ATC personnel.

3.7 Summary of the participants and methods of the thesis

The participants, methods and materials used in this thesis are summarised in Table 1.

Table 1. **Participants, material and methods of each study (I–IV) used in this thesis.**

Study	Participants	Material and methods
I	Organisation (internal) members, (e.g. ATC chiefs) Stakeholders (external members) Process groups in 4 ATC units Organisation members	Pre-interviews (n=16) Development plans (n=84) Post-interview (n=7)
II	ATM chiefs* Airport managers	Interviews (n=21)
III	ATC and AFIS personnel ATC and AFIS chiefs Airport managers	Open questions of a reporting system questionnaire (3 items, n=155) Safety culture questionnaire (11 items, n=142) Interviews (n=20)
IV	ATCOs (personnel and managers) in 27 units Safety and quality groups of 27 airports	Analysis of incidents (n=3136) using the HF tool Open questions of questionnaires (2 items, 46 questionnaires)

* The supervisor of an ATC unit is called the ATC chief in Studies I, II, III and the ATC manager in Study IV.

The participants, material and methods of the studies are described in more detail at the articles (Studies I-IV) and only the overall descriptions concerning them are included to this summary part of the thesis.

3.8 Validity

Threats to the internal validity of this thesis are addressed as follows because some conditions could lead to the wrong conclusions or results (Shannon et al., 1999).

This research arose from the practical needs of an organisation that was starting to implement HF. A qualitative method was chosen to gain deep insight into the meanings and purposes attached to HF by the managers and learning at work and to provide contextual information for these conceptions (Guba & Lincoln, 2007). Applying descriptive, qualitative approaches such as phenomenography (in Studies II, III) to analyse the data suited the study of a new topic in order to reveal aspects of the study participants and also problem areas for future studies (Vicente, 1997).

The categories of descriptions or types of conceptions (used in the final stages of the qualitative data analysis in Studies II, III, IV) were based on a relatively small amount of information and small numbers of study participants, and, naturally, there were no possibilities to calculate strict significant differences across the study groups – this was not even the purpose of the qualitative analysis. In Study II, categories of descriptions were used to determine the development phases of the managers' conceptions regarding HF. It must be remembered that these kinds of categories are not so clear and linear in real life, but still help to conceptualise results.

In addition, for some of the interview questions, there were few answers (Study II). This situation may reveal the difficulty of conceptualising the participants' own actions although there could be tacit knowledge concerning the area. It could also indicate that the interview questions were too general and not precise enough. Besides, the study topic was new in the organisation at the time of the data collection, and, naturally, the participants did not have the same conceptions as the researcher. The airport environment has very concrete jobs, and scientific language and concepts are unfamiliar there.

In the qualitative study, detailed tables helped the researcher to give some structure to the mass of data. The tables also give the reader the possibility to assess the validity and reliability of the final results when the raw data and the phases of the analysis can be concretely seen (Silverman, 2010). In this study, however, the phases of the data analysis were described (in Studies II, III), but they could not all be included to the original articles, or in this thesis, because of the limited space or the willingness to keep the text compact.

The choice of co-authors[5] from outside the organisation was important to assure that bias did not become a problem during the analysis of the data.

5 The co-authors of the articles (Studies I-IV) did not participate in the interventions or data collection during the studies, but did participate in the writing process after the data analysis. The co-authors were not working in the organisation but, instead, represented independent scientific research institutes.

3.9 Ethics

The codes of research ethics include several general principles. Their relevance is examined next, primarily according to Silverman (2010) and Denzin & Lincoln (2007).

Informed consent (Denzin & Lincoln, 2007) was obtained by informing the participants that they were being researched and also by explaining the nature and intention of the research to them.

The data of the studies used in this thesis were collected in several ways. In the case of the interviews (Studies I, II, III), the participants were volunteers, and they had the right to withdraw from the study at any time (Silverman, 2010, 153). Before each interview, the interviewees were told that the results would be used as material for this thesis. If quotations from the interviews were used (as in Study II), the participants and their units were coded. The questionnaires and incident reports were originally collected for the practical purposes of organisational development and safety work. In these cases (Studies III, IV), the privacy and identity of the participants were protected with the following safeguards: the data were collected anonymously, the results were handled in broader groups and the results or responses of individuals were not used in the reporting of the results (Silverman, 2010, 153–155; Denzin & Lincoln, 2007, 92).

During the work on this thesis, the author assessed the potential benefits and risks to the participants (Silverman, 2010); for example, publishing results regarding the HF application in the target ATM organisations offered organisation members an opportunity to reflect on their own thoughts about the work and safety of the ATM organisation, and also about the application of HF in the organisation. Different partners of the organisation (administration/HR, personnel/trade union, management) were asked about willingness to read the articles before the final thesis was published.

4.
Empirical studies

4 Empirical studies

4.1 From crisis to development – analysis of air traffic control work processes (Study I)

There are several positive effects regarding participative work and organisational development programmes, such as improved sense of community, collaboration, and efficiency (Robertson et al., 2008). In addition, the limited success of the interventions has been reported in relation to, for example, the lack of a long-term strategy, personnel participation or resources of the company regarding the intervention, or not taking the company's existing culture or internal power struggles into account (Zink et al., 2008; Hendrick, 2008; Leppänen & Lindström, 2009). It is also known that participants may have goals that differ from or are opposite to the formal written goals of the intervention (Büssing & Herbig, 2003).

A lack of systematic follow-up studies on past intervention outcomes has prevented researchers and practitioners from learning which initiatives have been effective (Schroeder et al., 2006; Elo et al., 2008), although they could show the actual costs and benefits of development projects (Kirwan, 2003; Hendrick, 2008), and the long-term consequences of projects (Elo et al., 2008). In safety critical domains, the development of a safety culture requires obtaining better data about the circumstances surrounding operative errors (Schroeder et al., 2006). The evaluation of HF projects still faces problems while savings may be underestimated; there is also the shift from the physical to the cognitive, social and organisational aspects of systems (Kerr et al., 2008).

In Study I, the aim was to evaluate the goals, results and consequences of the intervention in Finnish ATC at the beginning of the intervention, as well as during and after it. The intervention was started after an ATCO strike and aimed at analysing operative ATC work processes in order to improve co-operation between different actors in the organisation. An external ANS high level group initiated the intervention.

4.1.1 Methods

The evaluation of the intervention had three parts, with three kinds of data. In the beginning of the intervention, structured pre-intervention interviews (n=16) were carried out in 2001–2002, as a way for the researcher to understand the organisation in the context for the intervention and gain insight into the aims of the participants. The interviewees were selected using purposive sampling (Berg, 1995); they had to represent personnel, supervisors and top management, and administration, as well as some external stakeholders (because of their role as organisation clients or consultative experts). In the organisation, 13 people were interviewed, including personnel, managers or directors working in airports, ATC units or the head office. Outside the organisation, 3 persons were interviewed.

During the intervention, altogether 84 development plans were formed as a result of a systematic analysis of the work processes done by process groups in four ATC units (A–D). The units formed a varying number of plans, from 6 to 56 in each unit. The quantity and quality of the development plans were evaluated by classifying them according to their focus.

Six categories were used that were not created a priori but instead were determined on the basis of the data. The six categories were 1) co-operation, information flow, mutual understanding; 2) machines, systems, technical support; 3) training; 4) work, procedures, other tools; 5) policies, future organisation; 6) ergonomics.

Three to four years after the start of the project, structured interviews (n=7) were carried out (in 2005) to obtain information about the reminders and actions, and to determine the participants' opinions of the usefulness of the intervention. Those interviewed were ATC chiefs of the four ATC units (A, B, C and D), leading group members, and an ANS high level group member. Before coming to the follow-up interview, the ATC chiefs were asked to talk to their process group members about their recollections of the project. [All but one did this.] Only some of the original interviewees were invited to the follow-up interviews. In previous studies, it has been found that interviewing a supervisor (as a key person and representative) of the group produces reciprocal information for the whole group (Teperi et al., 1998). There was also the practical problem of calling back all of the participants several years after the project.

4.1.2 Results

There was wide agreement about the official project goal (which was the necessity to develop and analyse the ANS work environment) set by the ANS high level group at the beginning of the intervention. In addition, the following unofficial goals of the project were recognised: the ATC Association strived for reorganisation in which ATCOs would not be part of the airport organisation but would instead join the ANS department. Threats to the project were raised by all of the study groups except the stakeholders. Fear was mentioned about the possibility that the project would not being taken seriously, that the project would not result in permanent change and that only talk and paper work would start rather than actions. The external members did not talk about threats to the project, but they recognised the strong tensions between the different interest groups within the organisation.

The development plans concerned the most important needs of the work. Most of them dealt with co-operation (n=32, 38%), work arrangements (n=22, 26%) and machines/systems (n=12, 14%). The quality of the development plans varied across the units. ATC unit A raised numerous development needs that included practical details concerning, for example, work arrangements. ATC units B, C and D formed more integrated development plans, in which broader problems, such as work organisation or the future of the unit, were raised. In addition, the level of analysis differed among the process groups, ATC unit D representing a more analytic way of working during the intervention. ATC units B and C wished that process analysis would be a continuous process of discussion and development between personnel and management. Rare development plans[6] concerned a unit's own way of acting or thinking. This result is surprising considering the safety critical nature of ATM, but it is not totally a new phenomenon, while non-reflection and

6 In the target ATM organisation, a follow up was carried out in 2004 so that information about the actions resulting from the development plans of this intervention would be available. Most of the development plans had revealed discussions or actions in the ATM organisation. The practical actions were not the scope of Study I or this thesis, and they are not considered here in more detail.

even avoidance has been found in ATM workplace learning practices also before (e.g. Owen, 1999, 2009). In any case, this important finding of Study I motivated Studies II and III, presented later in this section.

After the intervention, it was evaluated as a whole. In the post-intervention interview, for the most part, the interviewees had positive ideas about the intervention and the methods used; the systematic way that the development needs and co-operation was brought to light during the project was mentioned in particular. Despite the positive experiences, most of the ATC units did not implement the activity in their unit after the intervention. The post-strike situation had been characterised by confusion, lack of mutual trust and tension between different parts of the organisation. The intervention helped serve as a therapeutic tool to move from crisis to normal worklife.

4.1.3 Discussion

Most of the interviewees agreed about the official goals set for the project by the ANS high level group. Congruence between the official and unofficial goals of development programmes is not always obvious. However, the aim of improving each member's own overall view of the whole ANS process was raised in only a few interviews, although this was one of the three official goals. This is astonishing when one considers the roles of the interviewees in the safety critical target ATM organisation. The unofficial goals (e.g. reorganisation) were not raised in the development plans at all. Therefore, the modelling tool served as an efficient tool for putting energy into the development of basic tasks.

The development needs raised by the process groups of the pilot units mainly concerned co-operation in and between the ATC units and the work arrangements of their own ATC unit. The development plans did not reveal the high level of self-reflection that has been noted as one key characteristic of the learning process (Schön, 1983) and professionalism. Experts, in comparison with novices, can apply self-criticism; they can figure out and explain the weaknesses of their plans and judgements in order to correct to their actions (Klein, 1998). The ability and willingness to improve one's own work, in spite of reflecting on other's characteristics, is crucial in critical work environments (Weick & Sutcliffe, 2003).

Study follow-up showed that development orientation was missing in the organisation, although single practical actions were put into practice in the ATC units. The organisation did not start a systematic work development process even though it had a clear need, as well as a concrete opportunity, to do so. This lack could be due to the weakness of the project organisation itself, but it could also have been an authoritarian feature of this organisation – top management did not force the method to be continuously used, and it was hard for individual persons to carry out work development activities alone. There was no competence and thus no appreciation of work development. In addition, a lack of resources (such as time) could explain the weak development orientation. The organisation had a post-strike situation during the intervention, with tension and contradiction between different actors of the organisation. In the different parts of the organisation, there could also have been the fear that the trade union would take even more power and use the work development programme for its own purposes.

Study I raised a question of how the managers of the whole organisation recognise the relevance of HF issues. Study II was motivated by the findings made in Study I (weak development orientation in the whole organisation), as well as by the fact, found in earlier studies, that managers' understanding regarding a new way of thinking (here, HF) has a crucial role in successful organisational improvements.

4.2 Managers' conceptions regarding human factors in air traffic management and in airport operations (Study II)

In dynamic, complex systems such as aviation, the human contribution has been recognised as a root factor in 80–90% of accidents and incidents (Reason, 1990; Wiegmann & Shappell, 2003). This feature may be due, for example, to the increased level of technology that demands a high human contribution in unstable environments with restricted resources (Kirwan, 2001 a, b; Dekker, 2002; Hollnagel et al., 2006). Organisations still have a tendency to evaluate safety on a micro level when it involves individual actions, errors or capabilities (Dekker, 2002; Wilson-Donnelly et al., 2005; Reason, 2008, 72). Despite active discussion and scientific research on HF, the assumptions, paradigms and conceptions that influence the way personnel and line managers in aviation organisations act and think still remain unclear (Hopkin, 1995; Korolija & Lundberg, 2010). The underlying assumptions, however, influence the way HF is put into practice in safety critical organisations (e.g. Leveson, 2011).

The aim of Study II was to determine whether managers see HF as a safety creating factor and what their conceptions of HF are in regard to theoretical developments in the field. The managers' conceptions with respect to HF were studied in order to determine the prerequisites for the pioneer work and the starting point in the organisation (the position of the HF expert had been created in the organisation 1.5 years prior to this study), and to determine the most effective means and methods of implementing HF work within the organisation in order to use it in improving the safety of services.

4.2.1 Methods

Structured interviews (n=21) were collected in 2006 from nine units with ATC and airport operations. The interviewees were ATC chiefs (n=11) representing middle management, and airport managers (n=9), representing upper management. The interviewees represented the following three functional environments: 1) radar units with heavy traffic (A I–II), 2) combined civil/military units (B I–IV), and 3) procedural ATC units (C I–III).

The interview had eight items, which were selected from the larger amount of interview data, and the selected items concerned the aims of the study (i.e. HF conceptions and the ways of dealing with HF both within the organisation and within one's own work unit. The airport managers were asked to answer the interview questions from the point of view of not only the whole airport, but also both airport operations and ATC.

The analysis of the qualitative data included three main phases. At first, several tables were formed to integrate and sort the interview data concerning each interview question, the responses of each person and three different functional environments. In this phase, ideas of grounded theory (Charmaz, 2006) were utilised, and there were no ready categories in which to classify the responses. Instead they were formed during the reading of the interviews. In the second phase of the analysis, the tables were summarised, and the frequencies of the answers were used to describe the contents of the data.

In phases one and two of the data analysis, the phenomenographic approach was applied for mapping the qualitatively different ways in which the interviewees conceptualised, perceived and understood various aspects of HF in the target organisation and in their own work (Marton, 1988; Uljens, 1989). Still, the authors wanted to have more concrete views of the phenomena under study, to determine concrete means with which to introduce HF into the organisation. The contents of the tables were further summarised on the basis of the emerging theoretical discussion concerning the HF conceptions.

In the third phase of the analysis, according to the interviewees' dominant way of perceiving the concept and the field of HF, they could be placed into five categories of descriptions that had been adapted and modified from models that represent the different ages of HF and industrial safety (Hale & Hovden, 1998; Hollnagel, 2004; Reiman & Oedewald, 2009). These were named "uninformed", "risk/error", "human recovery/ sociotechnical systems", "organisational", "complex, dynamic systems and resilience in these systems". An uninformed category was formed because not all of the interview responses could be placed into categories based on professional literature. The five-category model helped to determine whether there were some differences between the manager groups (ATC chiefs, airport managers) and the functional environments (study groups A–C).

4.2.2 Results

The managers' conceptions of HF revealed different development phases of HF and represented all five categories of descriptions; there were from two to eight managers in each category. The category "human recovery/sociotechnical systems" had six participants and the category "complex, dynamic systems and resilience in these systems" had eight participants. In both of these categories, the ATC chiefs represented the majority of the participants (i.e. four ATC chiefs, but two airport managers in the category "human recovery/sociotechnical systems", and five ATC chiefs, but three airport managers in the category "complex, dynamic systems and resilience in them"). In other categories, ATC chiefs and airport managers were equally represented, except in the "organisational" category, which contained only airport managers. Many of them pointed out limitations in the organisation (e.g. rigid decision making).

All of the respondents said that there was no unified or commonly shared strategy or vision regarding HF in their organisation; the interviewees' conceptions represented different categories regarding HF. According to most of the managers, an awareness of HF had been increasing in the organisation, and they had recognised some concrete actions regarding it (12 comments, of which 8 by ATC chiefs and 4 by airport managers). Some units had assessed the HF risks of co-operation or job contents using simulations or risk assessments. In addition, the reporting system had succeeded in highlighting HF. All of the managers had a role in the reporting system (e.g. in commenting on incident reports).

The conceptions of the managers of the radar units with heavy traffic represented the following categories: “uninformed”, “risk/error”, “human recovery/sociotechnical”, “organisational” or “complex, dynamic systems and resilience in these systems”. The managers of the combined civil/military units represented three different categories of descriptions: “risk/error”, “human recovery”, and “complex, dynamic systems and resilience in these systems”. Most of the managers working in procedural ATC units were placed into the “human recovery/sociotechnical” category, and some managers belonged to the “error” or “organisational” category. None of the managers of the procedural units ended up in the “complex, dynamic systems and resilience in these systems” category.

4.2.3 Discussion

In the current situation, managers’ disjointed and vague conceptions of HF can prevent the organisation from utilising HF competence in maintaining and developing the safety of services. The airport environment, as a complex, dynamic and uncertain environment, has the typical characteristics of complex systems (Vicente, 1999), in which, individual- or error-based conceptions are insufficient. Reflective ways of thinking and acting should be supported in order for work demands to be faced in the environments of ATC/airport operations (Norros, 2004). Conceptions that represent complex, dynamic systems and resilience would be a more versatile background for the ATC/airport operations.

The application of HF had supported some work units in making changes in operative work, which is an important commitment to a new area (Carayon, 2010). Managers should still have a more active role in applying HF; for example, they could train their subordinates in HF issues, but this activity would demand coherent training for all levels of the organisation’s management hierarchy first. There were some differences between upper and middle management regarding HF conceptions. The ATC chiefs were somewhat more concrete and produced more material concerning HF, possibly because of their training and work experience specific to safety issues. If management draws attention to certain aspects, it directs the actions of the whole organisation (Leppänen et al., 1997; Carayon, 2010).

The practical significance of the study is the identification of prerequisites that should be fulfilled before HF can become a true part of a high-reliability organisation culture and a key factor in the creation of safety. Firstly, a strategy and a key message from top management are needed, because these features commit the other manager groups of the line organisation. Secondly, HF is not a separate part of production but, instead, must be integrated into various organisation and safety management actions, such as audits, investigations, risk assessments and improvement procedures. Continuous training programmes for different professional groups must be developed, both for personnel and for managers. Thirdly, the work cannot be handled by one person only; instead implementation needs a team or network to act. Effective practical tools should be developed that are based on the latest theoretical findings, and organisational actors at every level should consider these tools useful. To keep an HF network alive, co-ordination is needed to create key informants and partners inside and outside the organisation.

The findings of Study II focused the researchers' interest towards learning skills in ATM. Learning competence is especially challenged when organisations try to improve their efficiency in the market (e.g. Ahonen & Virkkunen, 2003; Ahonen, 2008). But work process knowledge is also crucial for the creation of well-being at work (Leppänen et al., 2008).

4.3 Learning in air navigation services after initial training (Study III)

Aviation is considered a pioneer in learning. The learning techniques and actions that have been used successfully in aviation (e.g. simulations, CRM training; Helmreich et al., 1999; Salas et al., 2001) have been recommended to other high-reliability environments such as the nuclear power industry and offshore oil industries (Flin et al., 2002), the railways (FRA, 2007) and nursing (Dekker, 2007).

Effective means of continuous learning and research regarding these means will be important in the near future in aviation as the pressures for economic, technological, operative and political change grow (Rognin & Blanquart, 2001; Dijkstra, 2006; Oprins et al., 2006). However, aviation has not always been very dynamic with regard to change (e.g. Learmount, 2004); for example, in ATC, organisational features have constrained opportunities for learning at work (Owen 1999; 2009, Salas & Cannon-Bowers, 2001).

Although there is evidence that much learning takes place at work, relatively little is known about the way people learn informally in professional environments (Cheetham & Chivers, 2001). In aviation, aircrews have been actively assessed, but the ATC task is different, and scientific research into ATC training has been very limited (Oprins et al., 2006).

Study III aimed at determining the means and methods used by the target ATM organisation to further learning at work at the individual, team and organisational levels. The scope of the study was the continuation of learning during work after initial training (e.g. Do workers share experiences in teams, and how are incidents used as a tool for learning in work units?).

4.3.1 Methods

The data for Study III were collected using three methods over several years (2003, 2006, 2008), but the participant groups and themes remained the same.

The open questions of the reporting system questionnaire, which, as a whole, was an in-organisation survey, assessed the development needs of the confidential observation and occurrence reporting system in the organisation. Three open questions were selected for this study (see Section 3.4). In 2004, 308 questionnaires were sent, and 155 were returned, the final response rate being 50%. The participants were airport managers, ATC chiefs, ATCOs and officers and chiefs dealing with aeronautical flight information services (AFIS). The results were presented jointly to the study groups of the ATC and AFIS personnel (n=120), jointly to the ATC and AFIS chiefs (n=21) and to the airport managers in their own group (n=14). The AFIS persons were put into the same group with the ATCOs because the number of subjects was small (7 AFIS persons and 3 AFIS chiefs).

Four items of the semi-structured interviews (originally with 34 items of which 12 were used in Study II) were selected for use in Study III (e.g. "How and from what does an ATCO learn in his/her work?"; "What kind of training methods are used for ATCOs?"; "What is learning like in your unit, e.g. after an incident do you have a group discussion about it?"). Similar themes had been used and considered valid by researchers when they studied the prerequisites for a learning organisation in the Finnish paper industry in the 1990s (Leppänen et al., 1997). The interviews were recorded. Altogether 20 interviews were collected in 2006. Supervisors (9 airport managers, 11 ATC chiefs) of the organisation were invited from nine units that were big or medium-size in the context of Finland. The units represented enroute, terminal and aerodrome area ATC units.

A questionnaire using 11 items selected from the safety culture questionnaire (originally with 38 items) was used in the organisation in 2008 (the selected 11 items concerned especially learning). The basis for the questionnaire was a culture safety questionnaire that was formulated by Eurocontrol with the help of the University of Aberdeen (Eurocontrol, n.d./Mearns & Gordon). Most of the questions were reformulated by an HF expert of the organisation in co-ordination with a consultant, who implemented the questionnaire, to fit the local culture. The items assessed themes of reporting and learning ("I can bring up my mistakes and errors", "I get feedback on my report", "Corrective actions are carried out after the reporting", "The same mistakes keep on being repeated without any learning function"). The items were rated with values from 1 to 7 (1 = totally agree, 2 = somewhat agree, 3 = slightly agree, 4 = slightly disagree, 5 = somewhat disagree, 6 = totally disagree, 7 = do not know). There were originally 212 respondents from various professional groups from airports and units. Altogether 142 participants were chosen for this study (i.e. groups of ATC/AFIS personnel (n=102), ATC/AFIS chiefs and airport managers (n=40)) to keep the results congruent with the other data used in this study.

4.3.2 Results

As learning opportunities and situations in ATC work, such collegial learning as sharing ideas and working in pairs were considered important. The practicality of the training and learning from everyday work was stressed. In addition, on-the-job training and following aviation topics in the media supported learning after the initial training. Few comments were given concerning learning from successes or learning in coping with difficult cases in co-operation with others. Self-reflection was not actively mentioned by top management, but it was mentioned by the ATC chiefs.

Incidents and occurrences were somewhat used as learning material in working groups and units, several ways of collectively sharing experiences or other ways to put lessons learned into action were mentioned. Still, some interviewees (6) said that sharing experienced cases was very sensitive and that there were no get-togethers right after an incident. With the help of the reporting system, the respondents had learned alertness, as well as how to better understand error mechanisms and avoid the same mistakes and be proactive. Although feedback and actions of the organisation were experienced as weak, the reporting system had supported individual learning. Some participants wanted to develop the reporting system by having a possibility to discuss their own reports in the handling process of the report system and a possibility to read others' reports (22 comments in the open questions). The collective learning possibilities offered by the report system had also been missed, because the respondents had not always reported cases that they should have (reasons for this were found in 77 comments in the open questions, e.g. "very small things happened", "necessary actions were taken immediately afterwards"). According to the participants, they could bring up their mistakes, report them and use investigations to learn from them.

Feedback about reports and corrective actions were assessed as being weak. Some participants saw a risk of gaining a bad reputation because of active reporting. Other risks of the training system were also found: only some of the respondents were actively searching for information about the safety and quality group of their own airport or work unit, the blame was placed on others and the same mistakes kept repeating themselves without any learning function.

4.3.3 Discussion

Both individual and group means of learning were used in ATC. These means had both encouraging and discouraging characteristics from the development point of view. Although several ways to learn were considered after the initial training, they were adopted by some of the respondents, but not by the whole study group. This result indicates that the learning of respondents and units is not systematically supported in the organisation. It is also possible, as Owen (1999) has stated, that the complexity and temporal intensity of ATC work make it difficult to share reflections on work skills during everyday work. Thus especially work units with lively traffic would benefit from including reflection on cases during worktime.

The results of Study III (e.g. learning on an organisational level were considered weak sharing information was sometimes considered sensitive, others were sometimes blamed and top management did not reveal self-reflection) indicated that analytic or reflective learning is not a highlighted orientation in the organisation. The meaning of reflective work and a learning culture in complex systems has been highly recognised in safety standards of aviation and other high reliability industries (Norros, 2004; IAEA, 2006; ICAO, 2006). But results also show that there is a missing information flow about the actions taken or that personnel lack knowledge about the organisational processes and functions as a whole (Leppänen et al., 1997; Boreham, 2002). In addition, decision-making concerning actions can be slow, and results are seen only in the long run. Whatever the reason, there is a risk of frustration; when positive actions or feedback after problem reporting are not seen, there is a risk that reporting will stop and the organisation will lose learning material and possibilities for safety improvements (Leveson et al., 2006).

New forms of work organisation include interdependency between multiple producers (also clients) and require negotiated "knot working" and organised network expertise across boundaries (Engeström, 2000; Engeström 2004; Hakkarainen et al., 2004). The aviation-wide system has forums for sharing lessons learned, but it still raises questions about how aviation system level forums support learning at the national organisation level or how organisations learn from each other (e.g. how airlines, ANS providers and regulators share data and analyse it together).

The findings of Study III pointed to the need for a tool that could support organisational learning. Tools that support learning are especially crucial in the safety critical ATM organisation, where there is a risk of disturbances and incidents (Vicente, 1997; Kirwan et al., 2001; Schorrock & Kirwan, 2002). According to the previously found results of this thesis, in the target ATM organisation there had existed weak development orientation (Study I) and managers had vague conceptions of HF (Study II). This background motivated Study IV.

4.4 Application of a new HF tool in an air traffic management organisation (Study IV)

In order to improve the level of safety in a safety critical environment, a method for analysing incidents is essential. Traditionally, in incident analyses, the focus has been on factors causing problems. However, to motivate the ATC operators (here "ATC operators" refer both ATC personnel and managers) of the target ATM organisation in this study, it was considered important to highlight the positive role of human activity in coping with unexpected events, and the strengths and capabilities of human operators, rather than focusing on human errors and risks (Hollnagel, 2004; Hollnagel et al., 2006). Managers in particular play a crucial role in developing safety culture (Flin, 2006; Johnson et al., 2009). Thus it was considered important to aim at developing not only the personnel's, but also the managers', understanding of human risks, strengths and opportunities and, in this way, improve the safety culture of the organisation. The HF tool was to be used both by the ATC personnel and the managers (ATC operators) in the target ATM organisation to support the improvement of HF awareness and safety culture in the organisation.

Before the HF tool application, the possibilities of using previously applied HF tools and methods (e.g. SHEL, by Edwards, 1977; Hawkins, 1987 or HFACS based on the Reason model by Wiegmann & Shappell, 2003) to support organisational learning were considered, but the application or use of these tools was found to be either too time-consuming or they lacked the positive aspects of human behaviour.

Study IV aimed at reporting the application of the new, easy-to-use HF tool in the target ATM organisation. The active use of the tool by the ATC operators and the causal factors of the incidents identified by the ATC operators while using the tool were studied. In addition, the users' experiences with the tool and its use were evaluated.

4.4.1 Methods

The HF tool consisted of four parts (I–IV) that aimed at describing the individual (I), work (II), group (III) and organisational (IV) factors or characteristics that may contribute to the safety and efficiency of ATM operations. The method sees ATM as a sociotechnical system that is composed of psychological, technical and social elements (Vicente, 1999) (e.g. controllers, equipment and pilots as "external partners"), which are in continuous relation with each other (Roske-Hofstrand & Murphy, 1998; Leveson, 2011).

The application of the HF tool in the target ATM organisation included several phases. ATC managers were trained in the use of the tool as part of their safety management system (SMS) training, and ATC personnel received their training as a part of their basic or refreshment courses. During the training, the ATC operators received a checklist-type, "pocket size" HF tool (see Figure 7 in Section 3.6). They were requested to analyse each incident report using the HF tool, and to mark both positive and negative causal factors using the tool (until then the ATC operators had filled out, and commented on, incident reports without any additional tools).

The ATC managers started to use the HF tool before the ATC personnel did (in 2008), when the HF tool was used as part of the paper version of the confidential occurrence reporting system (COORS). In 2009, COORS was placed online (eCOORS), and the HF tool was included in this system. Thereafter, also the ATC personnel were requested to use the tool in evaluating incidents.

The use of the HF tool proceeded as follows: Upon receiving an incident report, the ATC operators were asked to evaluate the incident by marking the critical/suitable items of the case using the HF tool. They were not required to respond to all 47 items of the tool, but only to those that were considered critical causal factors of the incident in question. In 2008–2010, the ATC operators in 27 units analysed the negative and positive causal factors of 3163 incident reports using the HF tool. The active use of the tool and the causal factors of the incidents were studied.

The ATC operators' user experiences and the development needs of the HF tool and its use were studied using two open questions ("What experiences do you have of using the HF tool?", "How would you improve the HF tool or its use?") in 2008 and 2009. The open questions were included in the questionnaires, which were used as annual completions of the safety actions in each unit and were to be filled out by the safety and quality groups in each ATC unit (only ATC managers were members of these groups). In both 2008 and 2009, 23 units answered the questionnaires, and the open questions of 46 questionnaires were available for this study.

4.4.2 Results

The use of the tool was studied using the data of the ATC managers (not data from ATC personnel in 2008). Tool use varied from year to year and across the units. In 2008, ATC managers assessed an average of 68 incident reports per month using the HF tool (645 incident reports from a total of 1325 reports, 49% of all reports). In 2009, the ATC managers used the HF tool to assess 72 incidents per month (861 from 2485 reports, 35%), and in 2010, they assessed 134 reports per month (1210 from 2192 reports, 55%). The number of reports assessed using the HF tool increased each year, as did the number of reported incidents. The portion of HF-assessed cases decreased in the second year of use and increased in the third year. The ATC managers from 10 to 14 units used the tool actively each year in 2008–2010 and assessed 54% to 66% of the incident reports using the HF tool. Each year, moderately active users from 7 to 10 units assessed 21% to 28% of the reports using the tool.

The causal factors of the incidents analysed with the HF tool were studied using data received from both the ATC managers and the personnel. The portion of positive causal factors assessed by the ATC managers increased during the time period studied (from 14% to 49% of all the causal factors), and the most positive assessments concerned "individual characteristics" (e.g. situational awareness), which was Part I of the HF tool (especially in 2010; 40% of all causal factors). The most frequent negative causal factors assessed by the ATC managers were "work characteristics" (e.g. usability of technology, automation), Part II of the tool (from 23% to 32% per year).

The assessments of the ATC personnel concerning the negative causal factors of the incidents were distributed homogeneously (from 16% to 28%) across the individual, work, and organisational causal factors. The ATC personnel regarded their own "individual actions" as negative causal factors in 21% to 28% of all of the incidents. The ATC personnel and managers did not consider "group causal factors" (e.g. communication, Part III of the tool) to be significant causal factors of the incidents (from 6% to 13% of all causal factors). "Organisational factors" (e.g. co-operation between different actors, Part IV of the HF tool) were considered more as being negative (in 14% to 15% of cases) by the ATC managers and, similarly, also by the ATC personnel (16% to 19% of the cases).

According to the users' experiences (data from the ATC managers used to study this research question), HF tool use activated and committed the ATC units to analyse the causal factors related to the HF of incidents. It helped the ATC managers to commit to and learn the new field of HF.

4.4.3 Discussion

The organisation as a whole accepted the use of the new tool. However, there were differences in its use annually and across the units. It is not realistic to think that all of the users would take a new tool into use in all situations, because adopting a new tool requires that people are ready to commit themselves to a new way of thinking and to a new organisational culture (Pfeffer, 1992; Weick & Sutcliffe, 2001; 2003; 2007).

The benefits of the tool included its visual look, its user friendliness and the congruence of its contents with the earlier HF tools. The lessons learned that would support a more efficient use of the new tool were more extensive training, clearer instructions for the users, and publication of the actions based on the findings.

The use of HF competence in the target ATM organisation must be continued if the organisation is to be developed as a high-reliability organisation. The HF tool would support this future work. With the aid of more profound comparative methodological studies, the benefits of the developed tool can be further improved and also implemented in other complex sociotechnical systems.

5. General discussion

5 General discussion

In the current thesis, the application of HF to the target ATM organisation was studied over a period of 10 years, and, in this process, the factors supporting and hindering the application of new thinking and a new tool were evaluated. HF has been regarded as a crucial area of competence in the creation, maintenance and improvement of safety. A systematic sociotechnical approach is required in order to diagnose and improve the mastery of HF in an organisation.

In this thesis, a post-strike intervention in ATM was first executed and evaluated. The intervention aimed at developing and analysing ANS work using participative work process analysis in collaboration with different organisational parties. The intervention revealed the most important development needs of ATC work, but self-reflection did not emerge. The intervention was evaluated positively by the participants, but its results were not actively applied in the organisation afterwards. This situation raised a question about the existence of long-term, systematic, work development orientation in the target ATM organisation, which was run according to strict regulation with strong technical competence (Study I).

The thesis proceeded to study how managers of ATM and airport operations, as key persons in creating organisational culture, regard HF. It was found that managers had disjointed conceptions of HF, and there was no strategy regarding HF on the whole or in the target ATM organisation. This situation could prevent the whole organisation from utilising HF competence in maintaining and developing the safety of services (Study II).

To be able to realise HF, individuals, groups and organisations must learn both at work and from work and also use HF facts and principles in their work. Several ways to learn were found, especially at the individual level and variously at the group/unit level, but these means were not constantly evident. In addition, potential learning material (incidents) was weakly utilised in the attempts to improve work and safety, and therefore it seemed as if no systematic learning at work existed in the target ATM organisation (Study III). Finally, the target ATM organisation was able to adopt a new HF tool, thus realising a new work activity that involved analysing HF risks and resources of the operative work (incidents). This activity was included in their everyday operative reporting system. Although the use of the tool varied from year to year and across the units, it activated and committed the ATC operators and managers to HF (Study IV).

5.1 Development phases of the target ATM organisation regarding the mastery of HF

In this thesis, the application of HF is considered an innovation, a novel set of behaviours, routines and ways of working that are directed at improving the ATM outcomes or user's experience and that are implemented by planned and coordinated actions (Greenhalgh et al., 2004). And the application of HF is considered a way to improve the mastery of HF in the target ATM organisation, which has such development phases as diffusion, dissemination, implementation and innovation (Greenhalgh et al., 2004; Carayon, 2010).

The results of the thesis (Studies I, II, III) first indicated that the target ATM organisation did not have enough HF competence or methods to cope with the work demands of safety critical work, but, nevertheless, a willingness and need to improve HF competence arose (AIB, 1993; Final Report, 1999; Teperi, 2003). Using external experts' recommendations, the ATM organisation solved the organisational crisis with participative work development activities (Study I), which still seemed to be more like diffusion, a passive spread of HF actions.

A new concept of HF was launched in 2003. Thereafter several actions (e.g. investigation with HF contribution) were started (see Section 1.7, Figure 6). At that time, the HF application involved some active and planned efforts to convince target groups to adopt and incorporate HF as a new way of thinking and acting, thus indicating the dissemination or implementation of the HF application. From 2008 to 2010, the target ATM organisation adopted a new tool in everyday use (Study IV). Using this tool, it actually succeeded in coping with several of the weaknesses that had been found in earlier studies (e.g. lack of a systematic sociotechnical approach to the analysis of ATC work or the managers' weak role in HF) (Studies I, II, III). The prevalent situation can be considered to indicate that the HF application had been institutionalised and routinely used within the target ATM organisation – which, according to Carayon (2010), would be sustained as an innovation. Still, also innovations can be isolated and eventually subverted and abandoned (Schein, 1996). However, some findings showed that still not all of the cognitive and co-operative demands of ATC work had been recognised (Study IV), and there is therefore a need to continue systematic, long-term HF application in the target ATM organisation.

The development phases of the target ATM organisation regarding the mastery of HF have been summarised in Figure 8.

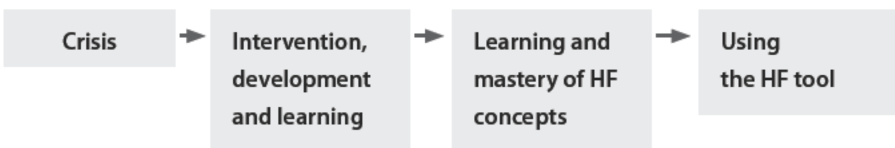

Figure 8. **The development phases of the target ATM organisation regarding the mastery of HF.**

It is widely known that every organisation faces supporting and hindering factors when trying to improve its functions or when implementing innovative work methods (Broberg, 1997; Hendrick, 2008; Kerr et al., 2008; Zink et al., 2008). Carayon (2010) has listed several hindering and facilitating factors of HF application, for example, in relation to the characteristics of the organisation and the actions of the HF expert. Challenges of HF application have also appeared in the nuclear power and process control industries (e.g. Kirwan, 2000; 2003) and in aviation (Owen, 1999, 2004; 2009; Wiegmann & Shappell, 2003).The supporting and hindering factors for the target ATM/whole organisation are considered as follows.

5.2 Factors supporting HF application

At the start of the HF application (in 2000, Study I), the target ATM organisation had a post-strike situation and a clear need for change. Using knowledge from the behavioural sciences was considered a promising solution to the problems of the target ATM organisation. In 2003, there was pressure on this organisation to improve quality and safety, and systematic HF work was started. The tension for change in an organisation was considered by Carayon (2010) to be one facilitating factor in the application of HF, and it probably helped the ATM target organisation to become more receptive to change, as well as more willing to accept or consider new ideas and suggestions.

External experts used the approaches of complex sociotechnical systems in the investigations of severe incidents of the target ATM organisation in the 1990s (e.g. AIB 1993; 1997). External consultants were also used in the post-strike situation (Study I). Such consultants are considered to be change agents who can act as catalysts and facilitators of change if they are believed to be credible and to have good interpersonal skills (Carayon, 2010), and if they have enough understanding regarding the operative environment, its history, procedures, culture and personnel (Robbins, 1996, 720; Kirwan, 2003).

The intervention in the target ATM organisation (Study I) succeeded in using the participative method to handle the work development needs, and conflicts among the different professional groups were solved. According to Carayon (2010), HF application is more easily accepted if the participants can see clear benefits in their work and if the constraints affecting their work are removed. Learning through and at work is also improved when operators assume the responsibility of analysing and developing their own work (Norros, 2004; Leppänen et al., 2008).

In Studies II and III, some of the personnel and managers of the target ATM organisation reported that activities regarding HF or workplace learning were active in their unit or in the ATM organisation. The HF expert had open group discussions with the ATC operators during the HF training, incident investigations and other HF activities (e.g. incidents were used as learning material during training sessions) (Figure 5). Carayon (2010) found the capacity for learning and listening, flexibility and good communication skills to be important for HF experts. These kinds of skills have also been highlighted in "coaching", a consultative form of participative leadership style that provides guidance, advice and encouragement to help employees improve their job performance (Robbins, 1996, 442; Kahai, Sosnik & Avolio, 1997).

The HF expert coached selected operators to become HF trainers in the target ATM organisation by transferring HF knowledge and material to this group, which became known as the HF network (Figure 5). Carayon (2010) has stated that the "train the trainers" model can be spread throughout an organisation, and, over time, it can disseminate HF knowledge and experience by taking on the role of an internal change agent. In addition, Robbins (1999, 720) has stated that, as change agents, internal staff specialists can support the desired change in employee attitudes, skills, experiences and perceptions within organisations.

The ATC operators adopted a new HF tool (Study IV). The tool aimed at facing the limitations found with the use of earlier applied HF tools or methods (e.g. complicated and time-consuming use) (Wiegmann & Shappell, 2003; Stanton et al., 2005). Carayon (2010) has stated that, in HF applications, there is a need to consider the workload of operative professionals and create new approaches that do not add to the already high workload of professionals and that new tools need to be devised, along with creative ways of applying HF in the system.

Management of the target ATM organisation received information regarding HF (e.g. HF causal factors of incidents) in monthly reports (Studies II, IV). A more systematic argumentation about the benefits of HF application was provided in 2008 for top management (Figure 5), and it was recommended that HF training be organised for top management in the near future (Studies II, IV). According to Flin (2006) managers have a crucial role in improving safety culture, and Carayon (2010) has stated that information needs to be provided to leaders and top managers so that they understand the potential benefits of HF in improving safety culture.

As a part of the HF application, the HF expert co-operated with other HF professionals, researchers and teachers (Figure 5). Carayon (2010) is of the opinion that HF experts, researchers and educators need to work together and form networks, and, in addition, inter-organisational co-operation by international safety bodies is considered to be an essential way of improving safety (e.g. ICAO, 2005).

The HF expert's task required a full-time job for 7 years. Resources for the HF work were provided, and several activities could be started in the target ATM organisation. The application of HF is successful if there is support and advocacy for HF within the organisation and if dedicated time and resources are allocated to the HF effort and if the HF expert is trained in, for example, issues of safety culture (Carayon, 2010).

The HF expert had a background in work and organisational psychology, and, based on this education and experience, she recognised some barriers to systems thinking (Study IV), professional boundaries (Studies I, II) and social networks during the HF interventions (Study I) within the target ATM organisation. Wiegmann & Shappell (2003) have stated that the background of an organisational (or OD) psychologist has been found to be a useful base for improving tools and frameworks for aviation psychology. Carayon (2010) has stated that, in order to develop approaches to cope with the organisational barriers faced during the application of HF, HF experts should be aware of the barriers.

5.3 Factors that hindered the HF application

The internalisation of HF was reasonably slow in the target ATM organisation (Studies I, II, III). It has also been noted that, before the 1990s, there was not much interest in HF issues or the cognitive ergonomic approach in the Finnish aviation industry (Norros, 2004). It can be wondered why the application of HF was not started earlier in the target ATM organisation or in the whole organisation (FCAA, Finavia) although there was a clear need for it (e.g. AIB 1993; 1997; ANS audit, 1998). The international regulatory bodies offered information regarding the relevance of HF in improving safety already 20 years prior to the start of the HF expertise in the target ATM organisation (e.g. ICAO, 1989). Scientific findings had offered information about mastering the demands continuously faced in such high reliability operative work since the 1970s (e.g. Vicente & Rasmussen, 1995). And already in the 1980s, the exploitation of information technologies and the resulting increase in automation in transportation systems had created a need to understand and support human operators' work activities in these highly demanding contexts (Norros, 2004).

The historical development of the whole organisation, as well as ATM as a part of the whole organisation, is described in the Introduction. The Finnish aviation administration and the target ATM organisation, as a part of it, have been a regulated monopoly without serious competitors, and it has a history of being a fragmented organisation (Hakola, 1997). Its production and functions have remained stable, for the most part, for decades (Hakola, 1997; 2007), and this situation may weaken the flexibility of the organisation with respect to changes in general (Robbins, 1996, 715). The whole organisation (FCAA, the state enterprise) was separated from the regulatory side reasonably late, in 2006. Besides, aviation history has gone hand in hand with the developments made in the military industry, especially wars have improved the infrastructure and technology used in aviation (e.g. Koonce, 1999). ATM development has been based on traffic volume and technological innovations (Hakola, 1997). In order to be successfully adopted, HF should be compatible with the adopter's values and norms (Greenhalgh et al., 2004; Carayon, 2010), and it is also known that an organisation's culture is formed and facilitated by its history and management (Schein, 1992). In the case of the ATM organisation discussed in this thesis, the history and culture have supported the creation of competence in fields other than the knowledge of human behaviour.

There was no strategy for HF or unified concepts regarding HF in the target ATM organisation (Study II), and managers of the organisation had not yet been systematically trained for HF (Studies II, IV). In the target ATM organisation, safety responsibilities had been defined in the safety management manual of the organisation since 2006. However, there was still some need to clarify the roles, and the manual did not include all of the HF actions implemented in the target ATM organisation. According to Carayon (2010), strategic barriers (e.g. unclear responsibility for safety across an organisation) can hinder HF application in organisations. It is known that strong leadership, a strategic and commonly shared vision and a climate conducive to experimentation are characteristics of organisations that are receptive to change and learning (Arvidsson et al., 2006; Leppänen et al., 2008; Carayon, 2010).

The results of this thesis point to the strong subcultures in the whole organisation, as also noted by the external consultants (Study I; also Hanski, 2002; Palukka, 2003). Different sections of the whole organisation (e.g. ANS, airport operations, techniques) had different historical roots, and the personnel had varying professional experience, education and training demands (Study II). The ANS functioning as an independent department was relatively new (Hakola, 1997), and it still struggled in establishing its professional identity in the 1990s (Palukka, 2003). The implementation of HF innovations can be particularly challenging if organisations tend to have strong professional boundaries and professionals tend to function within monodisciplinary communities (Carayon, 2010). According to Schein (1996), organisations fail to learn because of existing subcultures in the organisation, cultures of operators, engineers and executives. Each of these communicate with their worldwide occupational community outside the organisation in the sense that they have common problems that are unique to their roles – but the subcultures are not aligned with each other. There are indications of ATC being an autonomous professional group (Isaac & Ruitenberg, 1999; Palukka, 2003; Koskela & Palukka, 2010), but there are no research findings concerning the professional identities of the other professional groups (e.g. airport operations, administration) working in ATM or aviation administration organisations.

There had been tension among the professional groups in the whole organisation, and the ATCOs had fairly strong trade union politics to care for the group's privileges (Study I; Hanski, 2002; see also Palukka, 2003). This situation was widely recognised also by the media in 1980–1990 (numerous newspaper references, by Hanski, 2002 and Palukka, 2003). Trade union politics are extremely active in aviation worldwide and widely recognised in aviation business. The risk from the aspect of work development orientation is that ATC operators mix safety and politics in their activities. Because of experiences with strong interests in the past, the administration or executives make negative or rejecting interpretations concerning also the ATC operators' proposals, which could have been rational from the operative point of view and which could have helped operators cope with their work.

Actually, the challenge of strong subcultures and mixed conflicting interests is a familiar phenomenon also in other safety critical domains, such as search and rescue, hospitals and the military.

In the target ATM organisation, information was regularly given out regarding the HF results (Study IV). There were statistics in the different HF data (e.g. Study IV; Teperi, 2003), but there were no records or statistics available about the benefits of collecting the HF data. According to Carayon (2010), there should be a capacity and system in place for evaluating the actual and anticipated effects of the HF effort because a lack of evidence about what works can also hinder the application of HF. In addition, the cost-effectiveness of the HF application or programme should be demonstrated (Kirwan, 2003; Hendrick, 2008). The question of how to evaluate and demonstrate the "relative advantage" of HF innovations and the impact of HF applications on safety still needs to be more carefully addressed – does a decrease in human errors improve safety after all? (Carayon, 2010).

Study III concluded that there is a lack of, and a need for, an integrated learning system between different internal and external actors of the ATM system. Informal inter-organisational structures, quality improvement collaboratives and political directives, as well as efforts aimed at spreading HF innovations throughout the entire industry, have been found to be impacting factors (Carayon, 2010; also Schein, 1996). In addition, formal dissemination programmes by national and international organisations can facilitate the building of relationships between HF experts and operative organisations and policy makers. These were provided by several international regulatory and advisory bodies (e.g. Eurocontrol, 2008), but the resources of the small target ATM organisation were too limited for active participation in any but a few of the programmes.

In the target ATM organisation, changes in the organisational structure or work organisation were not made due to or concerning the new roles (HRD, HF), and, therefore, HF work was primarily carried out by itself for the first 5–6 years (Figure 5). If improvements are made only at the department or unit level, HF application can be hindered, when compared with situations in which improvements are made at the system level, so that structural patterns are formed in the organisation (Carayon, 2010).

There were signals indicating that, at the start of the HF application, there was no clear documentation or other preparation activities in the organisation prior to the HRD or HR vacancies (Study II). Carayon (2010) has stated that significant preparation and planning has to take place in an organisation in order for it to be ready for HF.

There also remains the question of whether the HF tool (introduced in Study IV) that was put into practice in the final phase of the overall HF application process in the target ATM organisation was adopted as a real tool that created new activity in the target ATM organisation or whether it was regarded as a new rule or norm (e.g. Engeström, 1987) set by the target ATM organisation – already and traditionally driven by norms and aviation regulation.

5.4 HF as a necessary tool for the target ATM organisation

The HF application in the target ATM organisation, introduced in this thesis, offered a good example of best practices for the way a small country with limited resources fulfils international (often strict) safety norms and regulations.

In the target ATM, and in the whole organisation, HF application was mainly included as a part of the SMS, which was an organised approach to managing safety, including the necessary organisational structures, accountabilities, policies and procedures (ICAO, 2009). The ANS providers are responsible for establishing an SMS, but also for regularly updating the included manuals, procedures and guidelines (existing regulations e.g. Commission Regulation (EC) No 2096/2005). Without HF knowledge and expertise ("safety thinking"), in addition to the traditional SMS, however, safety improvements may remain at the bureaucratic and official level, without any reform of workplace practices.

To advance safety, aviation organisations need to move beyond regulatory compliance; rulemaking has started to meet its limit of effectiveness (Dijkstra, 2006; Learmount, 2008). HF interventions offer possibilities for organisation members to explain, offer reasons for, or argue about the information behind the given safety norms, regulations or procedures (e.g. ICAO, 2009). This thesis indicates that, over a period of 10 years, the target ATM organisation started to become aware of the necessity of HF knowledge and began to realise that safety improvements demand HF competence.

The mastery of HF (actions or process of mastering HF, e.g. learning, studying and coping) is necessary for a target ATM organisation in order for it to maintain and improve the efficiency and safety of its services, as well as in order for it to maintain the well-being of its operators and management. Aviation safety is not only in the interest of a single organisation, it is also under the scope of social interest – new knowledge regarding safety improvements in safety critical fields is essential because their risks can have disastrous effects (e.g. Perrow, 1984; 2007).

5.5 Evaluation of the HF application and this thesis

From the start of aviation history, with a single person with his plane, the aviation system rapidly expanded manifold. Despite all of the technology, automation and infrastructure of the system, the human operator remained – and will remain – its core actor. As a part of the aviation system, ATM is one of the most complex systems, when compared with other work environments. Still, it is amazing how little interest, discussion and action human behaviour has raised in ATM – much less and much later than in the field of flight operations (also recognisable in the Finnish context). Human performance in ATM should be thought over more actively.

The HF application process described in this thesis tried to meet this challenge. An expert in human behaviour (HRD expert) was brought in to work in the organisation after an industrial action (a strike) in order to build up long-term activities in the ATM. It was rapidly found that solving problems from the HRD aspect is not enough or effective enough. The aspect, tools and frameworks of HF that were actually concretised by using the ideas of system ergonomics and participative development were needed to create the capability to act in the borderline between the operative (ATM, airport) environment and scientific knowledge regarding human behaviour. HF as a "content tool" helped the HF expert to communicate with ATM operators, and, through this effort, confidence was created between these two actors. Safety operations of ATM will, also in the future, be based on human skills, attitudes, motivation, work orientation and competence – not individually, but as a system.

There are several factors that could not be evaluated objectively by the author of this thesis. The dual role of the author of this thesis was perhaps one of its limitations and the role of the author as a HF facilitator, as well as HF researcher, can be questioned. Some means were used during the study to assure that bias did not become a problem during the analysis of the data. The co-authors of the studies on which this thesis is based were working in independent scientific research institutes. The co-authors did not participate in the HF interventions implemented in the target ATM organisation, but they did participate in the analysis of the intervention and the writing process after the project, filling the roles of advisors. Another way to assure that bias did not affect the analysis and conclusions was through the HRD/HF roles of the author in the organisation. As an expert on the whole organisation, she had to be careful not to base her estimate too much on any single partner of the organisation (e.g. administration, management or controllers). Instead, she tried to create an objective way to work and assess the organisation with the help of theoretically driven and empirically tested tools and work methods, such as the work process analysis used in Study I.

The author's dual role was also a strength of the thesis. The ATM organisation studied in this thesis is not easily accessed by a researcher outside its circle. As an inner organisation member, the author was able to form confidential relations with the operative personnel, as well as with the middle and top management, and these relations made the data collection for this thesis possible. This would have not been the case for an outsider. This lack of trust could also be one explanation for the lack of proactive change within the whole organisation – outside experts have not been very sensitively accepted. Due to the dual role of the author, she was able to implement participative intervention (a form of action research) as her methodological approach. As a result, the situation of the target ATM organisation improved, while, at the same time, it was being evaluated and researched. In addition, the dataset of this thesis can be considered skewed; however, it also represents several kinds of methods and types of data.

What should have been done differently in the HF application process? From hindsight, it is easy to note that the HF application would have been more successful if the resources of the HF work had been greater; in this process, teamwork and a network that co-operated on HF issues were formed reasonably late. In addition, there should have been more active contact with top management from the beginning. Such contact was not considered possible at the beginning, however. A stronger role for the supervisors (ATC chiefs/managers and supervisors) would have helped activate the HF application. Furthermore, the role of technology and the usability of automation was increased (Studies I, IV), and this problem could have been tackled with the models and tools of cognitive ergonomics – but, however, this approach would have been impossible to cope with within the scope of this thesis. This area should be handled more deeply in the future.

5.6 How to proceed in the future

The HF application in the target ATM organisation, introduced in this thesis, was a down-to-top approach to work and organisation development, which started with practical actions or interventions with personnel. In the future, the scope of the HF application should focus on actions of middle and top management, as well as on the system approach with several actors.

If the HF application is to proceed, the level of HF competence in the whole organisation (Finavia Corporation) should be evaluated objectively. HF competence means knowledge of, for example, human performance, equipment, systems, work environments and organisational behaviour in order to support safe, comfortable, and effective human performance. The knowledge required to design, implement and disseminate HF actions relies on the knowledge of basic scientific disciplines, such as physiology, sociology and psychology, as well as on such applied sciences as industrial engineering, business and management (FAA, 2005; Carayon, 2010). Regarding the whole organisation (and also other safety critical domains, such as the nuclear power industry), the question is what competence and knowledge is now necessary and, in the future, which professional groups should be recruited to the organisation, and how should these professionals with new knowledge be supported and helped with their work (also Ahonen, 2008).

If these issues are a part of the company strategy (as is recommended, Study II), HF professionals, such as experts in work development, education, sociology, information technology and related fields, should be regarded as professionals in the field of aviation and in the whole/target ATM organisation – and this has not been the case thus far. Traditionally, aviation professionals have been ATCOs, engineers and jurists – representing the subcultures of operators, engineers and executives (see Schein, 1996). If there is a willingness and motivation to use HF competence as a way of improving safety, the change is needed. Of the personnel of the whole organisation (approximately 1800 persons), few have the background suitable or congruent with the aforementioned HF competence (Finavia personnel, 2010) – and of those who do, few work with the HF issues (some activities in the HR unit with occupational health and safety issues).

The whole organisation (and the target ATM organisation as a part of it) is now in a development phase in which it is not a typical public sector organisation with public services (i.e. aviation administration), but it is not merely a private company functioning in free business markets either. Kickert (2001) calls these kinds of organisations "hybrid organisations" because they are somewhere between pure government agencies on one hand and commercial firms on the other. In these, public service tasks are related to modern organisational structure, with the aims of efficiency and client orientation – which would help in facing the challenges of the functional environment (Kickert, 2001).

For the top management of the whole organisation, successful HF application could provide added value in the form of efficiently and safely produced airport services. But will HF be focused on in the future when a new kind of a culture, a business culture, has risen within the organisation? The core idea should be that ATM business is business in the high-reliability domain (i.e. safety business; ICAO, 2009) and cannot be maintained without competence in safety thinking – which is the core of HF competence.

Lately, several researchers have been concerned, in several high-reliability domains, about situations in which economic goals exceed safety issues in organisational decision making. When safety improves in these organisations, the solutions used to improve the safety record are further optimised in decision making, driven by economic goals (Amalberti, 2001; Dijkstra, 2006; Perrow, 2007; Ek et al., 2007; Johnson & Kilner, 2010).

In order to improve the safety and efficiency of the ANS and other airport services, networks and system thinking should be empowered in the whole organisation. While the co-operation has traditionally been active with such "old actors" as the ministry, military side/air force, accident investigation officers and the regulator, "new" partnerships should be created with other safety critical, high reliability organisations (nuclear power, maritime, energy industry, health care), in order to benchmark safety critical processes and procedures of safety management, but also with universities and institutes in order to obtain knowledge of the latest findings and solutions concerning safety improvements. This orientation demands that the whole organisation recognise the characteristics found during the process of this thesis (Studies I, III), namely, complacency, a lack of self-reflection, "unlearnedness" and some introversion was found in the target ATM organisation, although the situation improved later (Study IV).

Without comprehension concerning the need for HF work also in the future, no persistence ("stamina") will emerge to make long-term activities in continuing HF possible in the organisation – and the HF application will continue to be only short-run adaptive learning ("doing better at what we are already doing"; Schein, 1996). Long-term HF activities demand a strategy regarding the implementation of HF in the organisation (a proposal with several stages in Study II; an example of a HF policy by FAA, 2005; prerequisites stated by Carayon, 2010). Without this, the activities will be "handicraft at the individual level", with several risks and hindrances, partly presented also in this thesis.

The process of designing the kind of a long-term strategy that is needed, and implementing effective interventions based on that strategy, has better possibilities to succeed if the work and findings of this thesis are first contemplated and discussed – and the findings are compared with the situation before this 10-year process began. Continuing the learning process (described in this thesis) is needed because it is the only way to proceed in mastering the demands of the future global ATM, which is becoming more complicated, dynamic and uncertain because of economic, political and social changes in the functional environment, which is also affecting small countries such as Finland (e.g. Dijkstra, 2006; Ek et al., 2007).

To summarise, the key message for the target ATM organisation (and the whole organisation), according to this thesis, is that, for the target ATM organisation, it is *nice to have* continuing HF awareness and training for different professional groups, but there *should be* active HF interventions managed by middle and top management – and, in order to get full value out of the former activities, there *must be* a HF strategy that will support future work in HF application so that the HF aspect is a solid part of the overall development activities of the whole organisation, and the results of the HF strategy are available and recognised in everyday operative work.

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