SINTEF REPORT

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TITLE

HELICOPTER SAFETY STUDY 2

Volume I: MAIN REPORT

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A/S Norske Shell, Statoil, BP Amoco, Elf Petroleum Norge AS, Norsk Hydro ASA, Phillips Petroleum Company Norway, Saga Petroleum ASA

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ABSTRACT

The present '*Helicopter Safety Study 2*' (HSS-2) is a successor of the previous '*Helicopter Safety Study*' (HSS-1) which was carried out and reported in 1989/1990. (See '*Helicopter Safety Study. Main Report*'. SINTEF Report STF75 A90008, Trondheim, 1990-11-01.)

Helicopter Safety Study 2, Volume I: Main Report summarizes the results of a study of the present and anticipated future risks associated with civil helicopter transport of personnel in the North Sea. (In this Report, "the North Sea" comprises the Norwegian and British Continental Shelf.) Some results are mainly relevant for the Norwegian Sector. Recommendations are given on how to improve the offshore helicopter flight safety during the next decade.

Seven Norwegian oil and gas companies have funded the main part of the study, in addition to the Civil Aviation Authority, Norway (NCAA).

Helicopter Safety Study 2, Volume II contains the Appendices of the main report.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Safety	Sikkerhet
GROUP 2	Helicopter	Helikopter
SELECTED BY AUTHOR	Helicopter safety	Helikoptersikkerhet
	Flight safety	Flysikkerhet
	Risk level	Risikonivå

Preface

This report summarizes the results of a study of the present and anticipated future risks associated with civil helicopter transport of personnel in the North Sea[1], i.e. the Norwegian and British sectors. The study is called "*Helicopter Safety Study 2*" (HSS-2) because it is a successor of the previous "Helicopter Safety Study" (HSS-1), which was carried out and reported in 1989/1990[2].

The project team wishes to extend our thanks to the initiators, Mr Jan M. Taarland, Statoil and Mr Erik Wiig, A/S Norske Shell, the other members of the Steering Committee and all other persons who, in one way or other, have contributed to the results.

The regular members of the Steering Committee consisted of the following representatives of seven oil and gas companies making use of civil helicopter transport for personnel in the North Sea:

Erik Wiig (Chairman), A/S Norske Shell
Bjørn H. Helgesen, BP Amoco
Gunnar M. Johannessen, Elf Petroleum Norge AS ,
David Williams, Norsk Hydro ASA
Øystein Borgersrud / Geir Stener Jakobsen / Eldbjørg Holmaas, Phillips Petroleum Company Norway (PPCoN)
Anne Mari H. Hereid / Jan Standal, Saga Petroleum ASA
Jan M. Taarland, Statoil.

In the capacity of regular participants, these companies funded the study on an equal basis. In addition, the Civil Aviation Authority, Norway (NCAA; Luftfartstilsynet) allocated funds in the final phase of the project, as well, among other things to encourage the propagation of the project results.

In the capacity of executing organization SINTEF Industrial Management participated in the Steering Committee with the following representatives:

Tor Ulleberg (Project Responsible)
Erik Jersin (Project Manager).

The following organizations were invited to the Steering Committee as observers. They participated with the following representatives:

Jens Kørte,	Helikopter Service A/S (HS)
Oddvar B. Riksheim,	Civil Aviation Authority, Norway (NCAA, Luftfartstilsynet)
Dag Johan Sætre / René de Jong,	Norsk Helikopter A/S (NORSK)
Ketil Karlsen,	Norsk Olje og Petrokjemisk Fagforbund (NOPEF)
Stein Rosengren / Tarjei Lodden / Ketil Karlsen	Oljeindustriens Fellessammenslutning (OFS), and Yrkesorganisasjonenes Sentralforbund (YS).

[1] In this Report, "North Sea" comprises the British and Norwegian Continental Shelf.
[2] See "*Helicopter Safety Study. Main Report*". SINTEF Report STF75 A90008, Trondheim, 1990-11-01.

The Project Team wants to extend our thanks to all of you for your guidance and kind cooperation during the whole project period. Furthermore, we feel that the employees at all levels in the two major helicopter transport companies in Norway deserve special thanks. These are Helicopter Service A/S and Norsk Helikopter A/S. Although being competitors their pilots, technicians and managers have exercised an exceptional will and ability to share their experiences and reveal their honest opinions on safety related matters.

Finally, our thanks are extended to the following persons who, although were not co-authors, have made significant contributions to the successful completion of the project:

- Stein Hauge, SINTEF Industrial Management, for identifying data sources and collecting data in the initial phase,
- Ragnar Rosness, SINTEF Industrial Management, for his contribution to the development of the risk model and his participation in the management interviews,
- Don Harris and his colleagues at Cranfield University, UK, for carrying out an expert judgement related to the British Sector, and
- Trond Winther, at that time a student, particularly for analysing accident reports and a great number of occurrence reports.

Trondheim, 1999-12-15

Erik Jersin

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Disclaimer

The conclusions in this report are drawn on the basis of several official databases, data from helicopter operators and expert judgements. The conclusions are subject to a number of assumptions and limitations stated in the report. SINTEF will accept no liability for conclusions being deducted by readers of the report. Caution should always be taken when using the results in the report, such that decisions are not taken on an erroneous or incomplete basis.

EXECUTIVE SUMMARY

1. Introduction

This is a summary of the main results of an investigation of the present and anticipated future risks associated with civil helicopter transport of personnel in the North Sea[3], i.e. the Norwegian and British Sectors. The study is named *Helicopter Safety Study 2* (HSS-2) because it is a successor of the previous *Helicopter Safety Study* (HSS-1), which was reported in 1990[4]. Some of the results of HSS-2 are mainly relevant for the Norwegian Sector.

It should be noted that in this Report, risk is measured as the number of fatalities per million person flight hours, unless stated otherwise.

The approach is based on the use of *Risk Influencing Factors* (*RIF*s). These are arranged in a Frequency Influence Diagram and a Consequence Influence Diagram, respectively. Turn up versions of these diagrams are located at the very end of this Main Report, as well as at the end of Volume II - Appendices.

2. Main conclusions

The main conclusions of the *Helicopter Safety Study 2* are as follows:

1) ***The risk related to helicopter transport offshore is significantly reduced since the first Helicopter Safety Study (HSS-1). With reservations due to the statistical variations there is an approximately 50% reduction in the average risk from Period 1 (1966-90) to Period 2 (1990-1998), see Figure 1 (data for the Norwegian and the British Sectors are combined here).***

2) ***According to the accident statistics there have been three fatal accidents in the North Sea during the period 1990-1998 (two in the English Sector and one in the Norwegian Sector). These statistics give a risk estimate of 1.9 fatalities per million passenger flight hours for the period 1990-1998 (Norwegian and British Sectors combined). In the Norwegian Sector, the number is 2.3, as opposed to 1.6 in the British Sector. Due to the low number of fatal accidents, it cannot be concluded whether the risk levels in the two Sectors actually differ.***

3. ***The estimated reduction in risk from 1990 to 1998 is 12%, see Figure 1. This estimate is based on a combination of accident statistics and expert judgement. The main contributing factors to this result are considered to be the following:***

- ***The implementation of the HUMS***
- ***Improved radar and radio coverage, and the separation of flight routes***
- ***The implementation of the NS-ISO 9000 series; "Quality Management and Quality Assurance Standards"***
- ***The introduction of several new types of helicopters***
- ***Improved aircraft crashworthiness (in particular impact absorption upon hard landings and stability on sea)***

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[3] In this Report, "North Sea" comprises the British and Norwegian Continental Shelfs.
[4] See *Helicopter Safety Study. Main Report.* SINTEF Report STF75 A90008, Trondheim, 1990-11-01.

4. ***<u>During the next decade (1998 - 2008) the assumed changes are expected to have both positive and negative effects on safety. However, the predicted net risk reduction is less than during 1990 – 1998.</u>***

5. ***<u>The main future threats</u> to helicopter safety are considered to be the following:***

   - ***An unfortunate change in the age composition of the pilots now operating in the Norwegian Sector of the North Sea, due to the forthcoming retirements of a large number of experienced pilots***

   - ***A shortage of fully qualified maintenance technicians***

   - ***Continued (or even increased) helideck problems, for example, due to an increased number of floating installations.***

   - ***A possible gradual and perhaps unnoticed risk increase due to a focus on cost reduction at the expense of safety issues, finally implying that the Helicopter Operators consider themselves compelled to operate close to the minimum requirements. If so, this could in some cases increase the risk of inadvertently going below the regulatory, minimum requirements.***

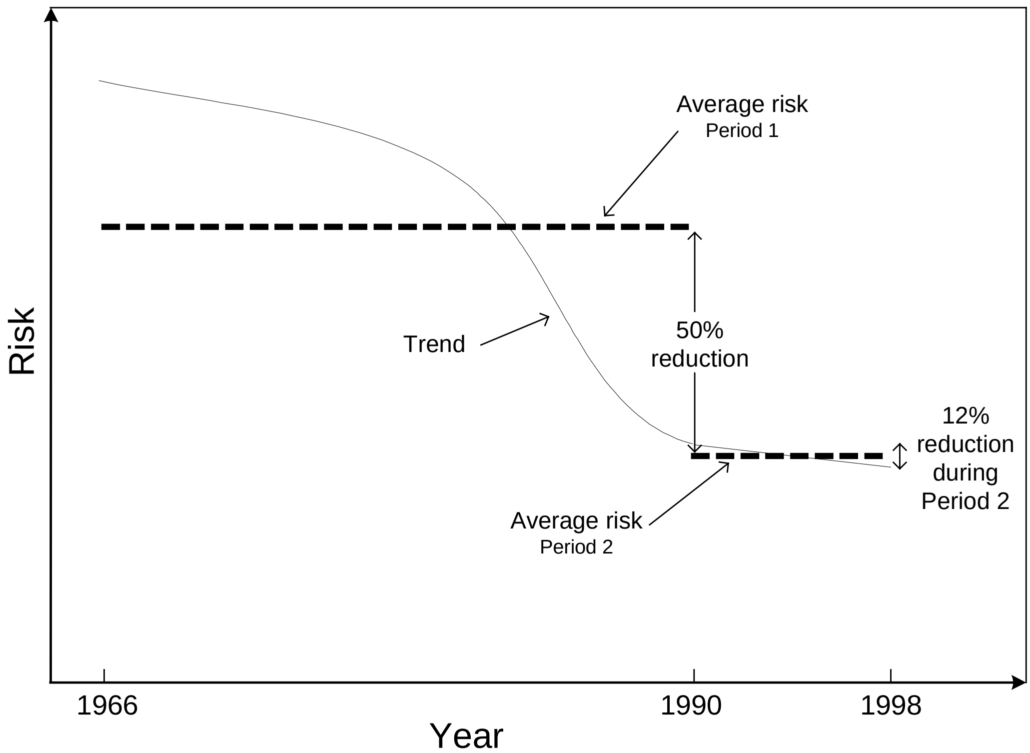

Figure 1. Illustration of estimated risk level for 1966-1998. Norwegian and British Sectors. The estimates of "Average risk" (Periods 1 and 2) are entirely based on the statistical data for these two periods. The given "Trend" for Period 1 (1966-1990) is included to give an indication of the assumed trend, whereas the given "Trend" for Period 2 (1990-1998) is derived from expert judgements.

6. ***The main recommendations for further risk reduction** are as follows:*

- ***During the next decade, the implementation of measures to reduce deviation[5] frequency should have priority over consequence-reduction measures. Based on the present situation the most important issues would be to improve helicopter Design and continuous airworthiness (RIF F 1.1 [6]), the Operator's maintenance (RIF F 1.2), the crew's Human behaviour (RIF F 1.6) and the Helidecks (RIF F 1.8). Together, these factors have contributed to almost 70% of the accidents that have occurred during the last decade.***

- ***Future changes in helicopter Design (RIF F 1.1) should primarily be initiated for safety reasons and not, for example, to further increase the aircraft payload and range. In particular, the HUMS should be made more reliable as a decision tool. The NCAA should also take an active part in the future development and use of HUMS. Furthermore, the rotor systems and the flight control systems should be further developed (made more redundant), and the performance with one engine inoperative should be improved.***

- ***In order to improve the Operator's maintenance (RIF F 1.2), it is recommended to extend the Crew Resource Management (CRM) concept to include the maintenance personnel, i.e. implement Maintenance Resource Management (MRM).***

- ***Close attention should be paid to the crew's Operations working conditions (RIF F 1.4), e.g. regarding working hours.***

- ***Pilot behaviour should be made even more uniform by enforcing firm Operations procedures (RIF F 1.5) combined with exercises (drills).***

- ***In order to improve the crew's Human behaviour (RIF F 1.6) it is recommended to***
  - ***promote experience transfer from experienced captains to younger pilots***
  - ***intensify the simulator training.***

- ***A set of safety-related Standard Contract clauses for all regular offshore helicopter transport should be developed and implemented. To this end, the Customers, the Helicopter Operators and the Trade Unions should join forces. In particular, such clauses should be designed to prevent cost-reduction considerations, even for minor measures and changes, result in a gradual reduction of safety margins (cf. item 5 above).***

- ***The NCAA and the ATS should develop the risk model further and adapt it to their needs. In addition, more specific safety objectives for offshore helicopter transport should be developed, and the NCAA should be engaged in more frequent risk analyses and trend analyses. The risk model and the analyses should form a basis for firmer Risk Informed Monitoring and Surveillance of offshore helicopter operations and maintenance.***

- ***A decision should be made regarding the controlled airspace issue, including the introduction of Automatic Dependent Surveillance (ADS) areas and routes.***

[5] Deviations include accidents, serious incidents, incidents and occurrences, cf. ICAO.
[6] Here *RIF F* refers to RIF for Frequency, see Frequency Influence Diagram

- ***Close attention should be paid to <u>Safety Management</u> in general, and <u>Flight Safety Programmes</u> in particular should be maintained (cf. JAR-OPS 1.3).***

3. Approach

The results of the HSS-2 project are derived by combining a *qualitative model* with a *quantitative model*.

The qualitative model is based on a number of *Risk Influencing Factors (RIFs)*, arranged in an Accident Frequency Influence Diagram and an Accident Consequence Influence Diagram, respectively; see turn-up versions at the end of this report. The *RIFs* in both diagrams are organized in three levels, i.e. “Operational” RIFs, “Organizational” RIFs and “Regulatory and Customer related” RIFs. All RIFs are characterized by their *status* (present state) and their *effect* (influence) on other RIFs. Arrows indicate the influence between one RIF and another, usually at the next upward level. Observe that the arrows (influences) at Levels 2 and 3 go both ways and that horizontal influences are not indicated in the diagrams for the sake of simplicity, even though they certainly exist in some cases. The small boxes entitled NA at Level 1 in the Frequency diagram refer to direct influence from the National Authorities (NA) at Level 3.

The Risk Influencing Factors (RIFs) will have a varying degree of importance for different types of incidents and accidents. Thus, the following eight *Incident / Accident (I/A) categories* have been defined:

1) I/A by take-off or landing on heliport
2) I/A by take-off or landing on helideck
3) I/A following critical aircraft system failure during flight
4) Near-miss or mid-air collisions (MAC) with other aircraft
5) Collision with terrain, sea or building structure (incl. CFIT)
6) Personnel I/A inside helicopter
7) Personnel I/A outside helicopter
8) Other/Unknown

The quantitative model is used to calculate how much the various RIFs contribute to the risk level. The model predicts changes in the risk level resulting from assessed changes in the RIFs. This is used to evaluate the effect of introducing various risk-reducing measures. In addition, the quantitative model is used to assess changes in risk during the period 1990-1998, and to predict future risk, i.e. in the next decade.

Risk (R) is given as the product of the *frequency* (*f*) of accidents and their average *consequence* (*C*), i.e. $R = f \times C$. In the present study, *risk* is measured as the number of fatalities per million person flight hours. The risk quantification has utilized the following sources of data:

- Accident and incident reports
- Deviation reports
- Expert judgements and workshops
- Questionnaires
- Management interviews
- Inquiries/reviews

HSS-2 has an improved model compared with the one used in HSS-1. The main changes / improvements are as follows:

- The HSS-2 model consistently complies with the ICAO definitions, e.g. regarding I/A categories.
- The HSS-2 model introduces some additional Risk Influencing Factors (RIFs).
- In HSS-2 the RIFs are arranged hierarchically in three levels, and are presented in influence diagrams.
- In HSS-2 the RIFs for accident frequency and the RIFs for accident consequence are treated separately.
- For Operational RIFs, the HSS-2 model distinguishes between *the status* of the RIFs and *the weight* (strength/importance) of the influence between RIFs.
- The mathematical formulation of the quantitative model is made more explicit in HSS-2. This makes the analyses re-examinable. Also, this change allows the analysis input to be varied in a simple way.

The changes are considered to be distinct improvements.

Norsk sammendrag av den statistiske analysen

- Norwegian Summary of the statistical analysis -

Nåværende risikonivå og trender

Det nåværende risikonivået for ulykker ved helikoptertransport i norsk og engelsk sektor av Nordsjøen[7] er beregnet på basis av ulykkesstatistikken for passasjerer og besetning sett under ett. Dessuten er trenden analysert, bla. hvordan risikoen har utviklet seg siden 1990, da den første studien ble rapportert[8].

Hovedkonklusjonene fra analysen av det tilgjengelige statistiske materialet kan kort sammenfattes i følgende punkter:

I perioden 1990-1998[9] inntraff det i alt 29 dødsfall for passasjerer og/eller besetning i forbindelse med personelltransport med helikopter i Nordsjøen (12 i norsk sektor og 17 i engelsk sektor). Dette tilsvarer i gjennomsnitt 1.9 dødsfall per million person-flytimer for norsk og engelsk sektor under ett (2.3 i norsk sektor og 1.6 i engelsk sektor)[10].

I perioden 1990-1998 har antall omkomne vært markert lavere enn i perioden 1966-1990[11]. For sistnevnte (1966-1990) inntraff det i norsk sektor i gjennomsnitt 4.1 dødsfall per million person-flytimer, mot de nevnte 2.3 for perioden 1990-1998. Noe forenklet kan en derfor si at risikoen for passasjerer og besetning - ifølge statistikken - er redusert med 45% for norsk sektor, når en ser de to periodene i forhold til hverandre. For engelsk sektor er den tilsvarende reduksjonen 50%. For norsk og engelsk sektor sett under ett er reduksjonen 47%.

Slike estimat for risiko er alltid beheftet med usikkerhet (p.g.a. statistiske variasjoner). I dette tilfelle er tallene dessuten følsomme overfor inndelingen av tidsperiodene. Hvis beregningsperiodene f.eks. forskyves til hhv. 1966-1986 og 1987-1998, vil statistikken vise at risikoen er redusert med 70% i stedet for 47%. Hvis derimot beregningsperiodene forskyves til hhv. 1966-1985 og 1986-1998, vil statistikken vise at risikoen er *øket* med 15%.

For å kompensere for de statistiske tilfeldighetene fra år til år er det også gjort trendanalyser, der en har benyttet såkalt glidende gjennomsnitt. Disse analysene viser at det synes å ha vært en markert nedgang i risikonivået (figur 0.1 og 0.2). Hvert punkt på kurven i **figur 0.1** representerer således gjennomsnittlig antall omkomne i 5 års perioder ("glidende gjennomsnitt"). Det første punktet på kurven (4 omkomne per million flytimer) er således gjennomsnittet av tallene for årene 1973, -74, -75, -76 og -77. Dette punktet er inntegnet midt i denne perioden (dvs. 1975). Det neste punktet (6.8) er gjennomsnittet for årene 1974-1978, inntegnet i 1976, og slik fortsetter det.

Som en ser av figur 0.1, faller kurven markert fra 1979 til 1981, stiger så en del, for deretter å falle til et enda lavere nivå fra 1988 til 1989.Til tross for de relativt store sprangene i kurven, er det rimelig å tolke trenden som generelt nedadgående de siste 20 årene. Den gjennomsnittlige risikoen i perioden 1966-1990 er 3.8 omkomne per million person-flytimer når norsk og engelsk sektor sees under ett. Risikoen de senere årene synes å ha stabilisert seg rundt den tidligere nevnte verdien på 1.9 omkomne per million person-flytimer.

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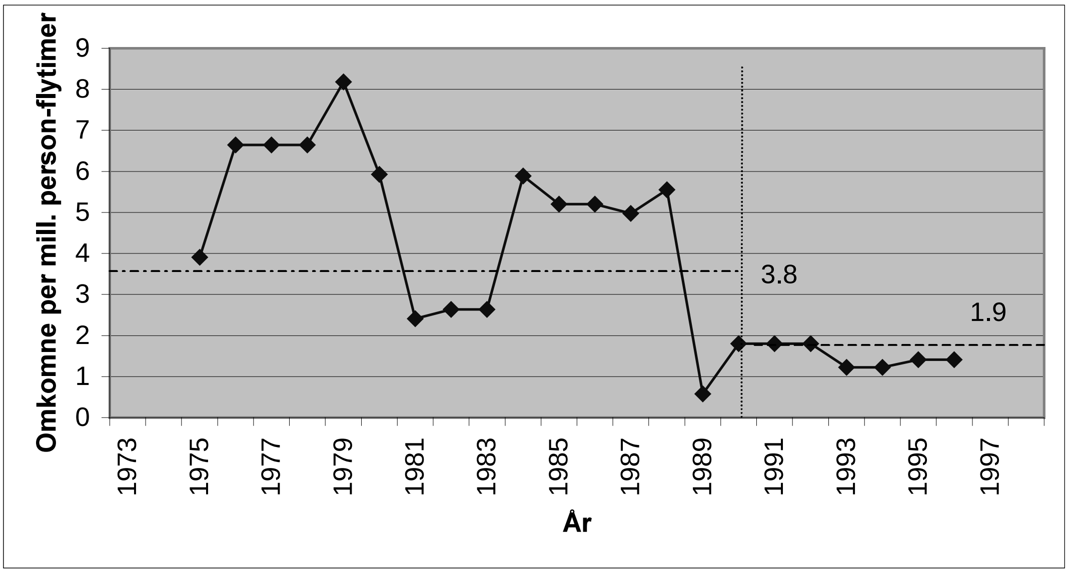
[7] Med "Nordsjøen" menes i denne rapporten norsk og engelsk kontinentalsokkel.
[8] Jfr. *"Helicopter Safety Study. Main Report"*. SINTEF Report STF75 A90008, Trondheim, 1990-11-01.
[9] Dvs perioden fra 1990-01-01 til 1998-12-31
[10] Ofte måles dødsrisikoen i *Fatal Accident Rate* (FAR) = antall omkomne per 100 millioner person-flytimer. De tilsvarende FAR-verdiene blir derfor 190, 230 og 160.
[11] Ulykkesdataene for den første studien gjelder fra starten av petroleumsaktiviteten inntil 1990-01-31



Figur 0.1 Risikonivået i norsk og engelsk sektor av Nordsjøen fra 1973 til 1998, fremstilt som 5-årlig glidende gjennomsnitt av antall omkomne per million person-flytimer.

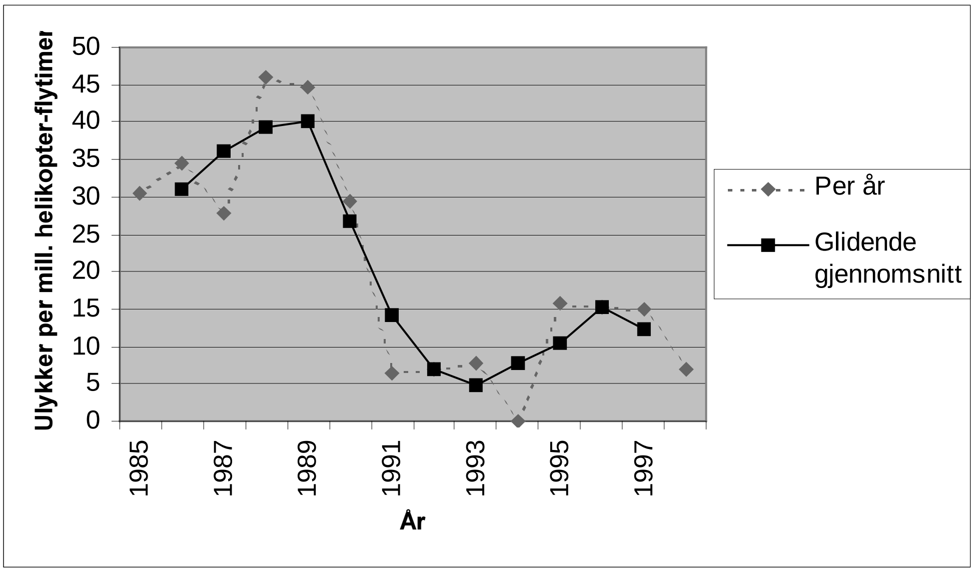
Antall omkomne er selvsagt påvirket av hvor mange mennesker som er ombord når en ulykke inntreffer. Antall passasjerer og mannskap er igjen avhengig av helikoptertype (passasjer-kapasiteten), hvor mye last og drivstoff som er med, foruten rene tilfeldigheter. For å underbygge påstanden om at risikoen har blitt mindre de senere årene, har en også studert hvordan antall ulykker har utviklet seg over tid i forhold til antall flytimer for helikoptrene, altså uavhengig av antall mennesker ombord. Dette gir også et mål som er underlagt mindre statistiske variasjoner.

Figur 0.2 viser hvordan antall ulykker per million helikopter-flytimer har utviklet seg for norsk og engelsk sektor i årene 1985-98. Den stiplede kurven viser den årlige hyppigheten, dvs. antall ulykker, beregnet per én million helikopter-flytimer. Den heltrukne kurven fremkommer ved å beregne glidende gjennomsnitt av antall ulykker i treårs perioder[12] (jfr. forklaringen til figur 0.1). Naturlig nok viser også disse kurvene et markert fall fra ca.1989 til 1993/94. Tendensen til stigning fra 1993/94 til 1996/97 synes å være tilfeldig.

Dersom en fordeler ulykker med dødelig utgang på de 8 ulykkeskategoriene som er definert i denne studien, finner en at systemsvikt i underveisfasen både står for det største antallet ulykker (47%) og de fleste omkomne (41%). Deretter følger landing på helikopterdekk, som svarer for 20% av ulykkene og 21% av de omkomne.

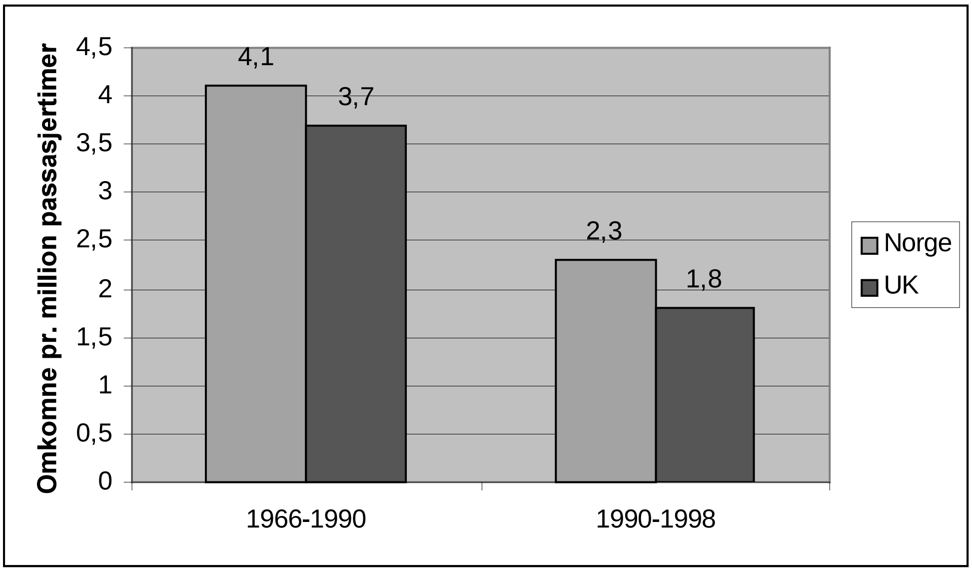
Det har ikke inntruffet noen kollisjon i luften mellom helikoptre eller mellom helikopter og fly i Nordsjøen. Det er likevel grunn til å være spesielt oppmerksom på denne ulykkestypen. Dette fordi det har vært flere tilløp til slike ulykker og fordi en slik kollisjon, f.eks. mellom to helikoptre fullastet med passasjerer, må antas å ha spesielt store konsekvenser.

[12] Glidende gjennomsnitt over tre års perioder benyttes ofte i internasjonal luftfartsstatistikk. Dataene fra 1985-89 er hentet fra CAA's årsrapporter. Tilsvarende data (antall ulykker) før 1985 har ikke vært tilgjengelig.



Figur 0.2 **Antall ulykker per million helikopter-flytimer i norsk og engelsk sektor fra 1985 til 1998, per år og som 3-årig glidende gjennomsnitt.**

Figur 0.3 viser estimert risiko (basert på ulykkesstatistikken) for henholdsvis norsk og britisk sektor, for perioden 1966-1990, som dekkes av den første studien (HSS-1) og perioden 1990-1998 (HSS-2)[13].



Figur 0.3 **Risikoen (målt i antall omkomne per million person-flytimer) ved helikopter-transport i Nordsjøen (norsk og britisk sektor) før og nå.**

[13] Når det gjelder risikoen for 1990-1998 for britisk sektor (1.8), gjøres det oppmerksom på at dette tallet inkluderer ulykker med omkomne utenfor helikopteret, fordi ulykker ble definert slik i HSS-1. Hvis disse ikke tas med (jfr. HSS-2's definisjon, reduseres tallet 1.8 til for perioden 1990-98 til 1.6 omkomne per million passasjertimer.

1. INTRODUCTION

1.1 Reader's guide

The results of this study are presented in two volumes, Volume I: Main Report and Volume II: Appendices.

Volume I, *Section 1 Introduction* presents the background, project objectives and some important prerequisites and limitations of the study.

Section 2 Approach explains the general approach and the use of Influence Diagrams in particular. Furthermore, the use of Expert Judgements is discussed.

Section 3 Project Results gives the answers to the questions inherent in the project objectives, see Section 1.3 below.

Section 4 Detailed Conclusions summarizes the results and gives recommendations for further risk reduction, i.e. during the next decade. In addition, possible threats to a further risk reduction are identified. The *Main Conclusions* are included in the Executive Summary.

Attention is drawn to the enlarged, fold out issues of the *Influence Diagrams* (Figures 2.2 and 2.3), which are included at the very end of both volumes of this Report. It is suggested to have these diagrams in view whenever referred to.

Volume II, Appendices gives important information on the basis for the reported project results. Particularly, attention is drawn to Appendix A1 and A2, which offer detailed definitions of the Risk Influencing Factors (RIFs).

1.2 Background, funding and project organization

In 1989-90 SINTEF carried out an assignment on behalf of A/S NORSKE SHELL and STATOIL to study the risks associated with helicopter transport in the North Sea. The final report, '*Helicopter Safety Study. Main Report'* (SINTEF Report STF75 A90008) was issued November 11, 1990. The report identified and described the most significant risk influencing factors and ranked those factors, which were supposed to have the greatest risk reducing potential. Since then, several of the recommendations have been implemented. For example, the "Health and Usage Monitoring System – HUMS" (a maintenance surveillance system) has been installed in many helicopters. There is, of course, reason to believe that these measures have significantly contributed to reduce the overall risk level associated with helicopter transport in the North Sea. However, some of the technical and operational conditions that existed during the previous study, hereafter denominated '*Helicopter Safety Study 1' (HSS-1)*, have changed. For instance, helicopter operations in the northern parts of the North Sea has increased significantly during the last years. Hence, a need to update the analysis evolved.

On request of STATOIL, SINTEF Industrial Management, Department of Safety and Reliability, in June 1997 worked out a Project Proposal concerning update of the first study. However, before a decision could be made regarding this proposal, a fatal accident occurred on a helicopter flight to the Norne platform in the Norwegian *Sector* of the North Sea. This, of course, drew a lot of renewed attention to both the real and the perceived risk associated with helicopter transport in this area. STATOIL, A/S NORSKE SHELL and SINTEF agreed that there was a need for a new, complete study – *'Helicopter Safety Study 2'* (HSS-2).

The following oil and gas companies operating at the Norwegian Continental Shelf, have funded the project and also constituted the Steering Committee:

BP Amoco
Elf Petroleum Norge AS
Norsk Hydro ASA
A/S Norske Shell
Phillips Petroleum Company Norway (PPCoN)
Saga Petroleum ASA
Statoil.

Further, the following Norwegian helicopter operators and organizations have participated as observers in the Steering Committee meetings:

Helikopter Service A/S (HS)
Civil Aviation Authority, Norway (NCAA, Luftfartstilsynet)
Norsk Helikopter A/S (NOR)
Norsk Olje og Petrokjemisk Fagforbund (NOPEF)
Oljeindustriens Fellessammenslutning (OFS).

The following companies and organizations have offered assistance of essential value to the project during the expert judgements etc.:

Helikopter Service A/S (HS)
Civil Aviation Authority, Norway (NCAA, Luftfartstilsynet)
Flygerforeningen ved Helikopter Service A/S
Flygerforeningen ved Norsk Helikopter A/S
Norsk Flygerforbund (NF)
Norsk Helikopter A/S (NOR)
Norsk Olje og Petrokjemisk Fagforbund (NOPEF)
Mekanikerforeningen ved Norsk Helikopter A/S
Oljeindustriens Fellessammenslutning (OFS).

Altogether, about 30 Norwegian helicopter pilots, technicians, union representatives and other persons have contributed directly to the project results. In addition, Human Factors Group at the College of Aeronautics, Cranfield University, Bedford, UK, has carried out an expert judgement in Aberdeen on behalf of the project, regarding the helicopter operations in the British *Sector* of the North Sea. This workshop involved about 10 British experts. Finally, some 40 representatives from the participating oil companies, the two Norwegian helicopter operators, NCAA, NPD and the Aircraft Accident Investigation Board, Norway (AAIB/N) attended a one-day management conference 24th November 1999 to discuss the findings and conclusions of the study.

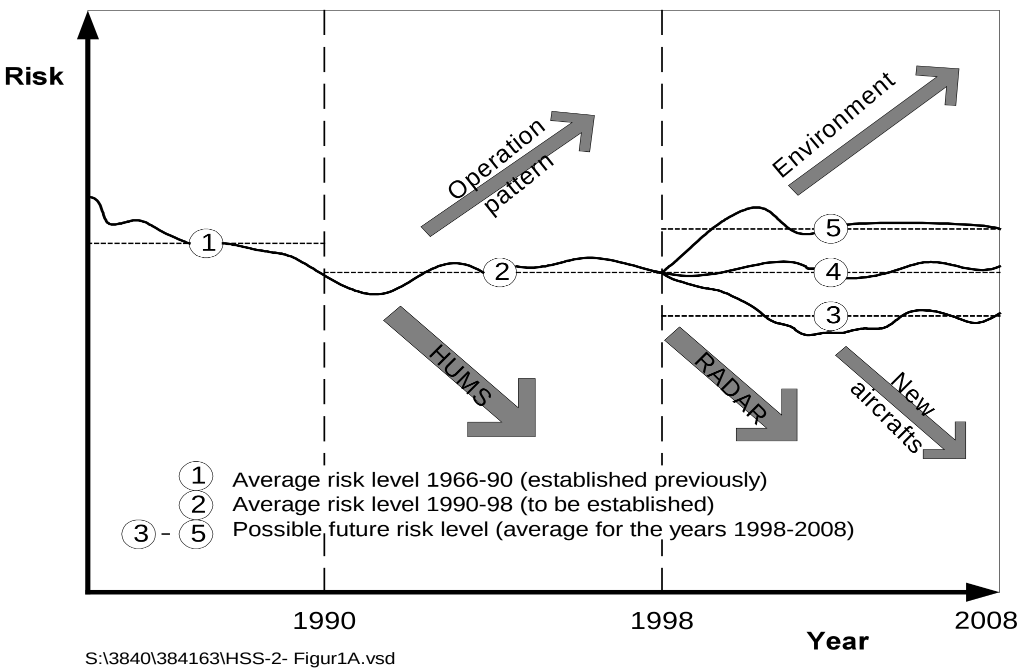
We greatly acknowledge the valuable contribution from all the above-mentioned, without whose enthusiastic efforts and support the project would not have been feasible.

1.3 Project objectives

The overall and main objective of the study has been "***to estimate the present (1997/1998) risk level associated with civil helicopter transport in the North Sea (i.e. the Norwegian and British Sector) and to give expedient recommendations regarding how to improve helicopter flight safety in this area for the next decade.***"

Figure 1.1 illustrates the objectives of the study in more detail. (Note that the figure is for illustrative purpose only.) *Risk Level 1* corresponds to the risk level established through the first Helicopter Safety Study (HSS-1). The first main task in this second study (HSS-2) was to estimate the *present* Risk Level (2), compare this with the former risk level and elaborate the reasons why the risk has improved or decreased. In other words, the effects of actual changes in relevant *Risk Influencing Factors* - RIF's (e.g. operation pattern, fuel reserves/alternates, HUMS, Radar etc.) during the years 1990 to 1998 should be established. In figure 1.1 these effects are illustrated by arrows, indicating forces. Based on this information, the analyses will provide recommendations for further risk reduction.

The next main task was to identify the planned and most likely changes in Risk Influencing Factors during the next decade, and to identify the Risk Influencing Factors that will have the most significant impact on the Risk Level in this period of time (presupposed that the recommendations actually would be implemented). Finally, the corresponding effects on the Risk Level in the next decade should be estimated. (3), (4) and (5) in Figure 1.1 indicate possible future risk levels.



Figur 1.1 The objectives of the Helicopter Safety Study –2 (HSS-2).

1.4 Prerequisites and limitations

One of the prerequisites of the present helicopter safety study was to utilise the methodology and results from the previous study (HSS-1), when relevant. Thus, efforts have been made to make the results of the two studies comparable. Consequently, risk level in both HSS-1 and HSS-2 is measured in fatalities relative to person flight hours (and for instance not relative to person km or helicopter flights, which are common alternatives). However, in HSS-2 there has been implemented some developments in the methodology of risk influencing factors, see Section 2.1 and 2.2.

The main limitations of study results relate to the field data. The statistical data of accidents/-incidents is rather sparse and is therefore subject to considerable statistical uncertainty. Furthermore, attention should be drawn to the fact that the civil aviation authorities in Norway and UK to some extent are using different criteria when classifying accidents, serious incidents and incidents. Hence, when analysing the reported accidents and incidents we had to exercise our own judgement. For further elaboration of the statistical uncertainty, see **Appendix B**, section B.5.

Also due to the scarcity of accident data, it has to a large extent been necessary to rely on expert judgements. In particular, when it comes to judgements concerning the effect or importance of the RIFs and changes in RIFs over time, expert judgements provide a substantial part of the input. However, when possible, these judgements have been used in combination with actual data.

Risk levels in the present report refer to regular offshore passenger traffic only. Thus, accidents related to training flights, test flights and SAR operations are excluded. In general, such operations have a higher probability for accidents than regular flights. However, the consequences are often less, as fewer persons are usually involved.

Finally, the model, as described by the influence diagrams, of course represents some simplifications. Influence diagrams are intended to capture *major* influences, and will not include all effects or influences that might exist. For example, in order to avoid a too complicated model, no horisontal arrows have been included. Furthermore, the simultaneous effects of two or more RIFs are not explicitly modelled. Thus, one RIF *alone* might have only a slight effect on the risk, but in combination with another RIF it might have a major effect. The overall result could be that a "moderate" effect of this RIF is included in the model.

1.5 Definitions

In this Report, the following definitions are used:

Risk Influencing Factor (RIF)
A set of relatively stable conditions influencing the risk. (RIF is *not* an event and it is not a state that fluctuates over time)

Operational RIFs (RIFs at Level 1)
Risk influencing conditions related to ongoing daily activities necessary to provide safe and efficient offshore helicopter *transport* on a day to day basis. The activities include conditions

concerning aircraft technical dependability, state of aircraft operational dependability and provision of necessary external services.

Organizational RIFs (RIFs at Level 2)
Risk influencing factors related to the organizational basis, support and control of running activities in helicopter *transport*. These factors are related to helicopter manufacturers, operators, air traffic/air navigation services, and helideck/heliport operators.

Regulatory and customer related RIFs (RIFs at Level 3)
Risk influencing factors related to the requirements and controlling activities by authorities and customers.

Influence diagram
Visual representation of (i) the relation between the *Risk Influencing Factors (RIF*s) and the risk related to the various incident/accident categories (I/A), and (ii) the interrelationship between various *RIFs*.

Accident
An occurrence associated with the operations of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, in which a person is fatally or seriously wounded, or the aircraft sustains damage or structural failure, or is missing or is completely inaccessible[14].

Incident
An occurrence, other than an accident, associated with the operation of an aircraft which affects or could affect the safety of operation.

Controlled Flight Into Terrain (CFIT)
CFIT occurs when an airworthy aircraft, flown by a properly trained crew, is flown into water, terrain or an obstacle without the crew being aware of, or becoming aware too late to prevent, the impending collision[15].

Landing decision point (LDP)
The point used in determining landing performance from which, a power-unit failure having been recognised at this point, the landing may be safely continued or a baulked landing initiated[16].

Take-off decision point (TDP)
The point used in determining take-off performance from which, a power unit failure having been recognised at this point, either a rejected take-off may be made or a take-off safely continued[17].

Deviation
An event that reduces the intended level of safety and has such consequence or potential consequence that it is reportable to the authorities. Deviations are categorised into accidents, serious incidents, incidents and occurrences.

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[14] See ICAO Annex 13 for the complete definition.
[15] Reference is made to Flight Safety Foundation
[16] Reference is made to JAR-OPS 3.480 (a)(9)
[17] Reference is made to JAR-OPS 3.480 (a)(22)

Note: Determining whether a deviation is to be categorised as an accident, a serious incident, an incident, or an occurrence may, in some cases, be subject to discussion. The statistics presented in this report is solely based on the categorisations made by the aviation and aircraft accident investigating authorities of the United Kingdom and Norway for deviations that have occurred in the British and Norwegian *Sector*s, respectively. Even though both states have similar definitions (based on ICAO Annex 13), slight differences in categorisation practice cannot be ruled out.)

Serious Incident
An incident involving circumstances indicating that an accident nearly occurred.

Note: The difference between an accident and a serious incident lies only in the consequences[18].

Occurrence
A *deviation* not categorised as *accident, serious incident,* or *incident* due to its less severe consequence or potential consequence.

Fatal Accident Rate (FAR)
The number of fatalities, due to accidents, per 100 million person flight hours.

[18] Examples of serious incidents can be found in Attachment D of Annex 13 and in the ICAO Accident/Incident Reporting Manual (Doc 9156).

1.6 List of abbreviations

AAIB	Air Accident Investigation Branch
ACC	Area Control Centre
ADS	Automatic Dependent Surveillance
ADS-B	ADS-Broadcast
ADS-C	ADS-Contract
AFIS	Airdrome Flight Information Service
AFM	Airplane Flight Manual
ANS	Air Navigation Service(s)
ATC	Air Traffic Control
ATS	Air Traffic Service(s)
BSL	The Norwegian Civil Aviation Regulations (Bestemmelser for Sivil Luftfart)
CAA-N	The Civil Aviation Administration, Norway (Luftfartsverket)
CAA-UK	The British Civil Aviation Administration
CFIT	Controlled Flight Into Terrain
CRM	Crew Resource Management/Company Resource Management
CTA	Control Area. An area of controlled airspace extending upwards from specified limit agl.
DGPS	Differential Global Positioning System
DNMI	The Norwegian Meteorological Institute (Det Norske Meteorologiske Institutt)
FAR	Fatal Accident Rate (fatalities per 100 million person flight hours)
FBW	Fly By Wire
FOM	Flight Operations Manual
FPSO	Floating Production, Storage and Offloading Unit
GPS	Global Positioning System
HFIS	Helicopter Flight Information Service
HFM	Helicopter Flight Manual
HLO	Helicopter Landing Officer
HO	Helicopter Operator
HS	Helikopter Service A.S
HSS-1	*Helicopter Safety Study* (reported 1998/90
HSS-2	*Helicopter Safety Study 2* (this report)
HUMS	Health and Usage Monitoring System
I/A	Incident/Accident
ICAO	International Civil Aviation Organization (the UN's agency for civil air traffic)
IHUMS	Integrated Health and Usage Monitoring System
JAA	Joint Aviation Authorities
JAR	Joint Aviation Requirement
LDP	Landing Decision Point
LO	The Norwegian Federation of Trade Unions (Landsorganisasjonen i Norge)

MAC	Mid-Air-Collisions
M-ADS	Modified Automatic Dependent Surveillance (System)
MET	Meteorology
MoDU	Mobile Drilling Unit
NA	National Authorities
NCAA	Civil Aviation Authority, Norway (Luftfartstilsynet)
NMD	Norwegian Maritime Directorate (Sjøfartsdirektoratet)
NOR	Norsk Helikopter A.S
NORSOK	Norsk Sokkels Konkurranseposisjon
NPD	The Norwegian Petroleum Directorate (Oljedirektoratet)
OLF	The Norwegian Oil Industry Association (Oljeindustriens Landsforening)
Pax	Passenger
PFT	Periodic Flight Training
PPCoN	Phillips Petroleum Company Norway
QA	Quality Assurance
RIF	Risk Influencing Factor
RIF C	RIF for Consequence
RIF F	RIF for Frequency
RIFx.y	RIF no. y at Level *x* (*x* = 1, 2, 3) in the influence diagrams
SAR	Search and Rescue
SOP	Standard Operating Procedures
STC	Supplemental Type Certificate
TDP	Take-off Decision Point
VFR	Visual Flight Regulations

2. APPROACH

In this Chapter 2 the risk model for the Helicopter Safety Study –2 is discribed. First, the *qualitative* model is presented, based on

- Incident/accident categories (I/A)
- Risk influencing factors (RIFs), arranged in influence diagrams.

The use of the model in the analysis of accidents/incidents is also referred. Finally, an outline of the *quantitative* model and the data sources is given.

2.1 General approach and ambitions

The model is based on the introduction of *Risk influencing factors (*RIFs*)*. A "RIF" is a relatively stable factor, affecting the risk of helicopter traffic. Examples are "Operators maintenance", "Operations procedures" and "Air traffic / air navigation services". The RIFs are defined in **Appendix A1** and **Appendix A2**.

A main objective of the modelling task carried out in this study is to establish a relationship between the *RIF*s and the risk of passengers/crew in offshore helicopter traffic. In the *qualitative* analysis so-called *influence diagrams* are utilised to model both the *frequency* and *consequence* of accidents. These diagrams visualise the interrelationship between various *RIF*s, and the relation between *RIF*s and the risk related to the various incident/accident categories. The influence diagrams will by their graphical interface ease the communication/discussion concerning the relevance of the various *RIF*s to the overall risk. These influence diagrams are also used for accident classification and analysis.

The risk is here quantified as the number of fatalities (of passengers/crew) per million person flight hours. In Section 3.1 statistical data are used to assess the *average* risk level for the time period 1990-98. The *quantitative* model will demonstrate how much the various *RIF*s contribute to the risk level. By use of this model we can predict changes in the risk level resulting from specified changes in the *RIF*s. This is used to evaluate the effect of introducing various risk reducing measures. Further, the model is used to assess change in the risk over the period 1990-98, and to predict the *future* risk.

2.2 Comparison with the HSS-1 Model

The HSS-2 model is an enhancement of the model used in the previous helicopter safety study ('HSS-1'), see [Ingstad et al, 1990], and of models used in subsequent projects at SINTEF with a related approach, e.g. see [Holden et al, 1997], [Werenskiold et al, 1998]. The present model is also based on influence diagrams, and similar approaches are reported e.g. in [Embrey, 1992] and [Paté-Cornell et al 1996].

Main changes/improvements of the model, compared to the model of the previous helicopter safety study ('HSS-1') are:

- In order to ease the communication between experts and non-experts, the influence relationships between RIFs and the accidental events, and between the RIFs themselves, have been clarified by means of a graphical interpretation (*influence diagram*). Furthermore, the RIFs have been arranged hierarchically, i.e. in various *levels*.
- The structure of the model allows utilising *deviation data* (incl. *accidents* and *incidents*) in an efficient and explicit way.
- As far as practical the *ICAO* definitions have been used to obtain consistency with today's established terminology.
- Some *new RIF*s are included, in addition to those treated in the previous study.
- The mathematical formulation of the quantitative model is made more explicit, which makes the analysis re-examinable, and allows in a simple way to vary the analysis input.

2.3 Incident/Accident (I/A) categories

The *RIF*s are likely to have a varying degree of importance for different types of incidents/accidents (I/A). Thus, the incidents and accidents are split into eight categories. These I/A categories are adapted from the previous study (HSS-1), although some adjustments have been made to emphasise the fact that we are analysing occurrences, incidents and non-fatal accidents as well as fatal accidents. Further, the category *Unsuccessful emergency landing,* used in HSS-1 is not a specific I/A category in HSS-2, but is included in I/A 3 (see below).

The I/A categories are defined to be exhaustive and mutually exclusive (i.e. each deviation belongs to one and only one I/A category). The definitions of the I/A categories in HSS-2 are as follows:

1) I/A by take-off or landing on heliport
I/A initiated after the passengers have boarded the helicopter and before the Take-off decision point, or after the Landing decision point and before the passengers have disembarked at a heliport.

2) I/A by take-off or landing on helideck
I/A initiated after the passengers have boarded the helicopter and before the Take-off decision point, or after the Landing decision point and before the passengers have disembarked at a helideck.

3) I/A following critical aircraft system failure during flight
I/A caused by critical aircraft system failure initiated after the Take-off decision point and before the Landing decision point, e.g. in main rotor, tail rotor, engine, gearbox etc. When a critical aircraft system failure has occurred, the aircraft (crew/pax) can only be saved through a successful emergency landing.

4) Near miss or mid-air collision (MAC) with other aircraft
Near miss (loss of separation) or collision with other aircraft during flight, although no critical systems have failed.

5) Collision with terrain, sea or building structure

I/A following collision with terrain, sea, or other obstructions initiated after the Take-off decision point and before the Landing decision point, not caused by a critical system failure (I/A no. 3). This category (no. 5) is mainly a CFIT accident, but it also includes collision with terrain, sea or obstructions for other reasons.

6) Personnel I/A inside helicopter

Injury to persons (crew/pax) inside the aircraft, e.g. caused by toxic gases due to fire or cargo.

7) Personnel I/A outside helicopter

Injury to persons (crew/pax) located outside the aircraft, e.g. tail rotor strike on helideck or heliport. Hazards to personnel other than crew and passengers are not included.

8) Other/Unknown

Any I/A not categorised into category 1)-7). This could include e.g.

- I/A caused by lightening,
- Technical failure of aircraft (or human failure of crew) occuring on heliport/helideck before the passengers have boarded the helicopter or after the passengers have disembarked,
- I/A caused by sabotage or person with mental illness (no cases have occurred),
- I/A due to aircraft being hit by vehicle on heliport (no cases have occurred).

2.4 Risk Influencing Factors (RIFs) and Influence Diagrams

Deviations are defined and classified in accordance with the ICAO standard as

- *accidents*,
- *incidents* and
- *occurrences.*

The ICAO definitions of these deviation types are given in **Chapter 1.5**. In the present study, risk is measured by the number of fatalities. Thus, we could restrict to consider *accidents*. However, statistical data on all of the above three *deviation* types will be utilised when relationships between the RIFs and the risk is established.

The overall risk model is illustrated in **Figure 2.1**, and applies regardless of the I/A categories. Only "generalised" *RIF*s and influences are included there, and the discussion of the detailed model is deferred to **Sections 2.5 - 2.9**.

A *risk influencing factor (RIF)* is defined as a set of relatively stable conditions influencing the risk. It is *not* an event, and it is not a state that fluctuates over time. RIFs are thus conditions that may be influenced/improved by specific actions. Starting at the top of the diagram in Figure 2.1, the risk is quantified as the product of the *frequency* (f) of accidents and their average *consequence* (C)

$$R = f \times C.$$

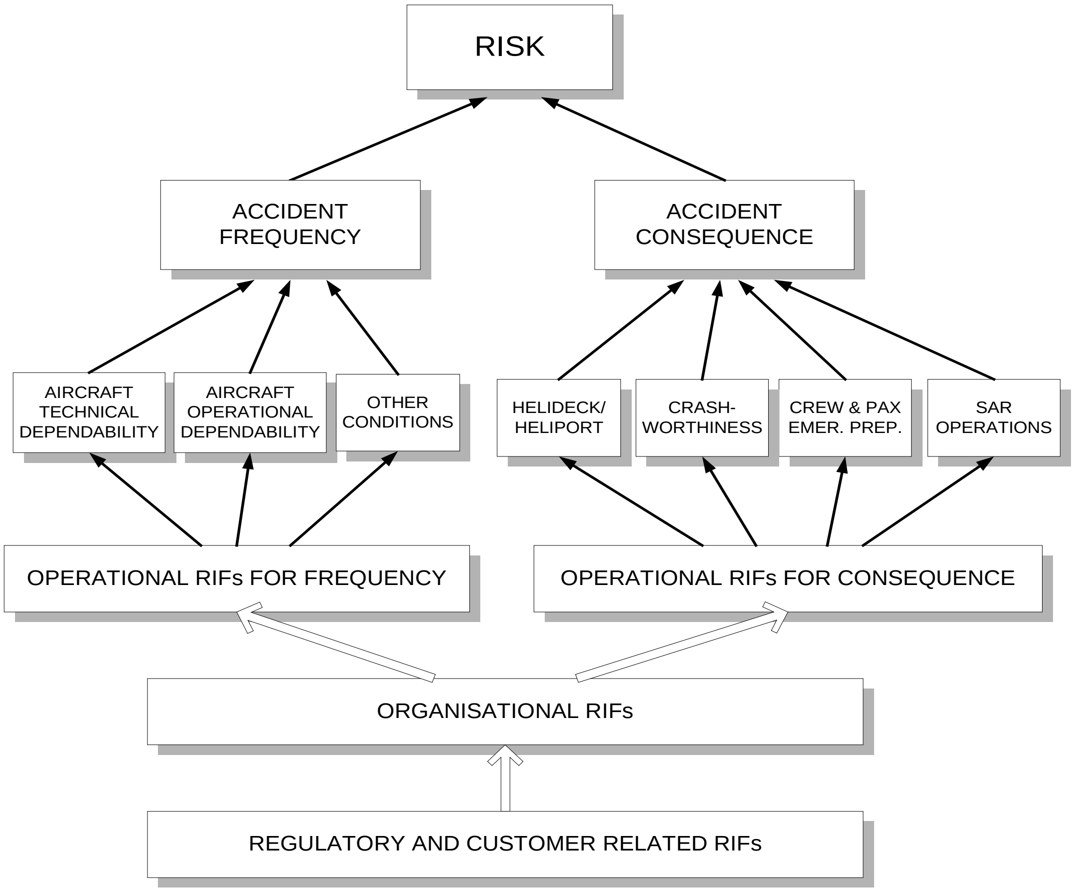

Figure 2.1 Outline of general risk influencing model

Accordingly, the *RIF*s are split into two broad categories of 1) risk *frequency* influencing factors and 2) risk *consequence* influencing factors. According to the model in Figure 2.1, accidents (and more generally deviations) are assigned to one or more of three main causes ("frequency categories"). The causes can be related to loss of:

- *Aircraft technical dependability*
- *Aircraft operational dependability*, or
- *Other conditions external to the aircraft.*

Similarly, four main categories of consequence factors are identified:

- Helideck/Heliport
- Crashworthiness
- Crew and Pax emergency preparedness
- SAR operations

These frequency and consequence categories are in turn influenced by Risk Influencing Factors (*RIF*s). The *RIF*s are organized in levels according to their direct effect, and the levels are defined as follows (also see Figure 2.2 and Figure 2.3):

- *Operational RIFs*, for frequency and consequense respectively, are defined as risk influencing conditions related to running activities necessary to provide safe and efficient offshore helicopter *transport* on a day to day basis. The activities include conditions related to *requirements* concerning aircraft technical dependability, state of aircraft operational dependability and provision of necessary external services.
- *Organizational RIFs,* defined as risk influencing factors related to the organizational basis, support and control of running activities in helicopter *transport*. These factors are related to helicopter manufacturers, operators, air traffic/air navigation services, and helideck/heliport operators.
- *Regulatory and customer related RIFs,* defined as risk influencing factors related to the requirements and controlling activities from authorities and customers.

The presise definitions of the RIFs are provided in **Appendix A1** and **A2.**

2.5 The RIFs for accident frequency

The frequency model is illustrated in **Figure 2.2**. (Note that enlarged, fold out issues of Figures 2.2 and 2.3 are included at the very end of both volumes of this Report.) **Appendix A1** gives the definitions of the *RIF*s shown in this diagram. The "boxes" of this influence diagram are arranged in the following levels:

- Incident/Accident (I/A) category
- Main causes of the I/A (Level 0)
- Operational RIFs (Level 1)
- Organizational RIFs (Level 2)
- Regulatory and customer related RIFs (Level 3)

Each box at levels 1-3 represents a RIF, and the *status* and *effect* of the RIF influence the status of the RIFs it is connected to at the level above. The *status* of a RIF is a measure of "good" or "bad" state with respect to factors affecting the safety of helicopter operation. For example, the status of the *National Authorities (NA)* influences the status of the *Helicopter Operator*, the *Helideck and Heliport Operators* etc. Most of the arrows in the diagram go from one level to the next level above. However, this is not a requirement, as we can see e.g. by the arrows from the *National Authorities* to the *ATS / ANS*, indicating a direct influence from regulations to operation. Observe that, in order to reduce the number of arrows and to simplify the figure, there are no *direct* arrows from *National Authorities (NA)* to the RIFs two levels above. The relevant influences are indicated by small boxes titled (*NA),* connected directly to the RIFs in question.

The *strength* of the influence between the boxes in the diagram will vary. For example, the influence from *Design and continuos airworthiness* on the *Aircraft technical dependability* could be stronger than the influence from the *Operator's maintenance*, indicating that a "bad state" of the former should be given a higher *weight* with respect to the I/A - frequencies. This will be reflected in the quantification by the *weights* of the RIFs, see **Section 2.9.**

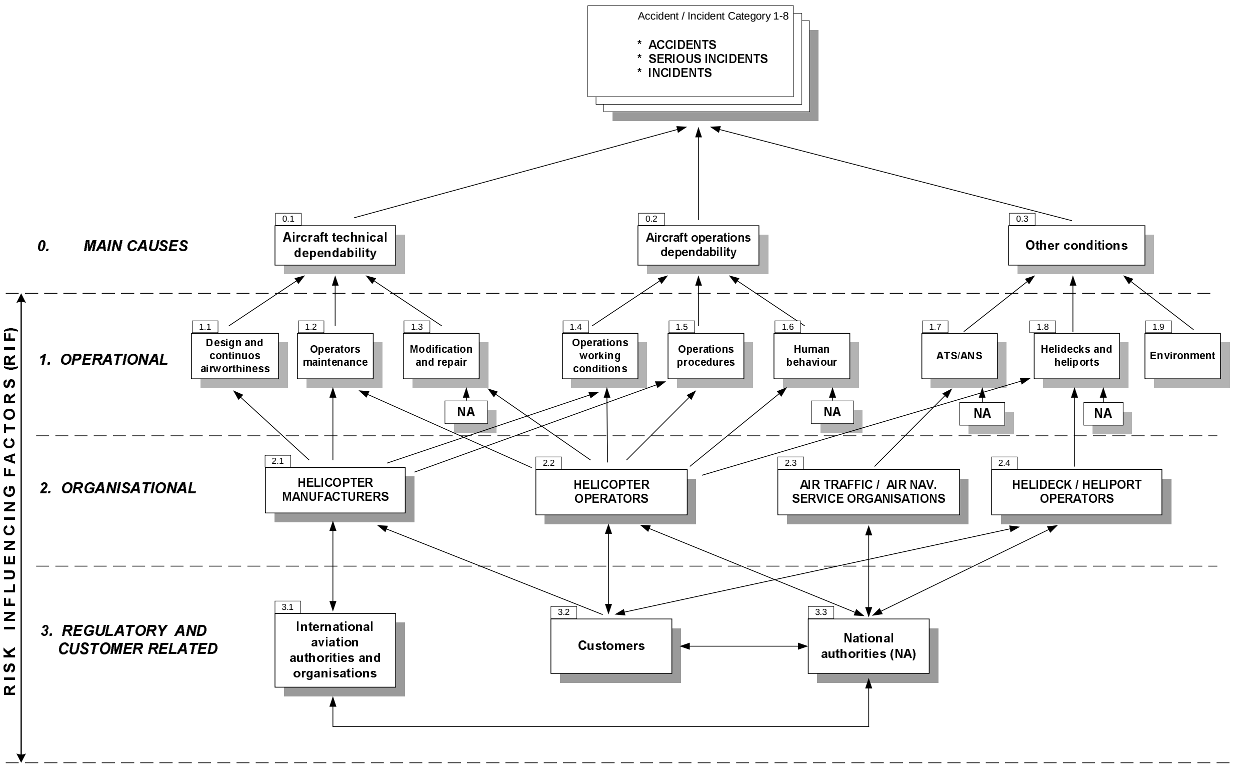

Figure 2.2 Influence diagram for the frequency of accidents/incidents

In principle such a model is established *for each I/A category*, and the final result is derived from each of these models. However, for simplicity one frequency and one consequence model, *common* for all I/A categories are presented here. Differences amongst the I/A categories are reflected in variations in the strength of the influences indicated by the arrows.

2.6 The *RIF*s for accident consequences

The consequence part of the model is illustrated in **Figure 2.3**. (Note that enlarged, fold out issues of Figures 2.2 and 2.3 are included at the very end of both volumes of this Report.) **Appendix A2** gives the definitions of the *RIF*s shown in this diagram.

The interpretation of the boxes and arrows are the same as for the frequency model described above, and is not repeated here.

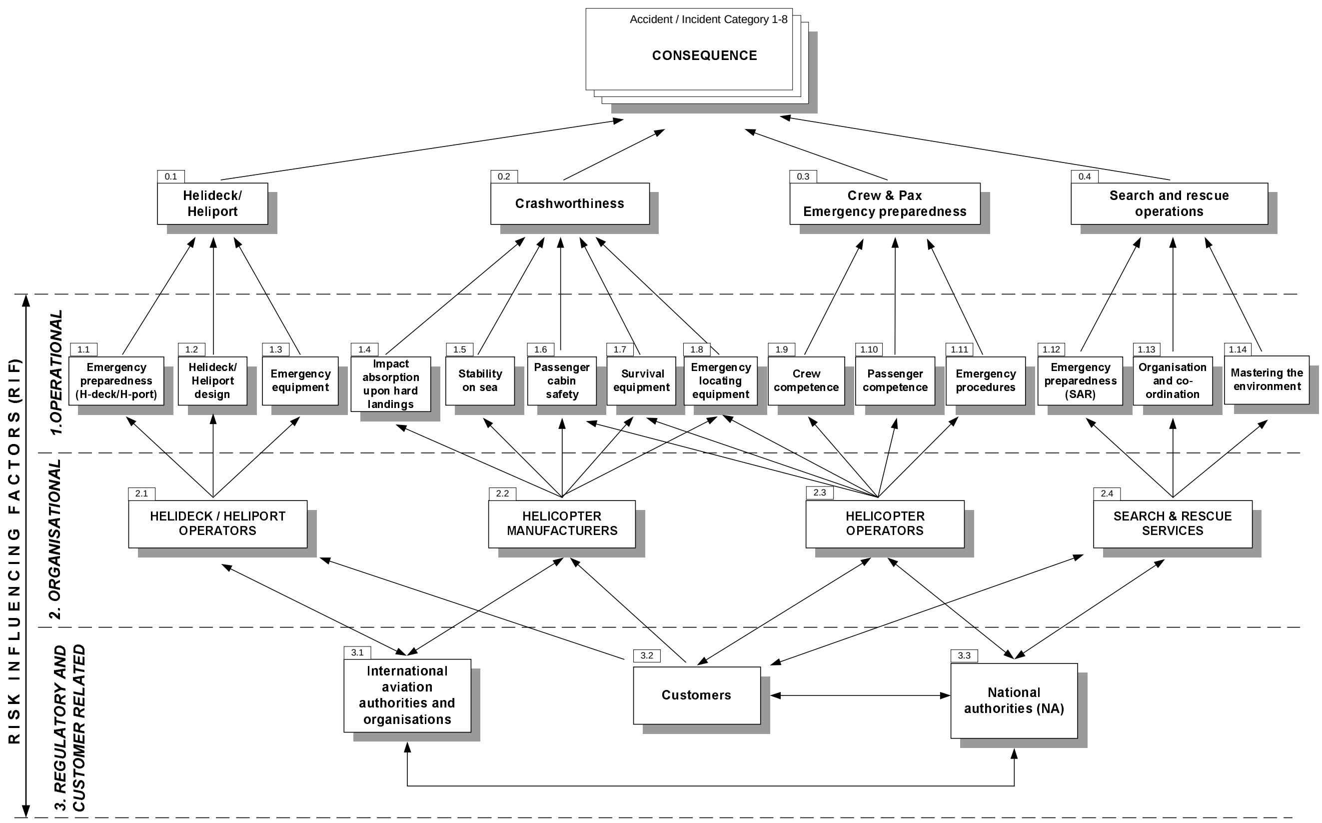

Figure 2.3 Influence diagram for the consequences of accidents/incidents

2.7 Use of influence diagrams in Incident/Accident Analysis

The risk model is used for various purposes:

- to illustrate the influences, (as described above),
- to provide a tool for analysing and classifying accidents and incidents,
- to *quantify* the risk improvement potential (as will be discussed in **Section 2.9**).

Here the 2nd of these three applications of the model is discussed, considering analysis of *incidents* and *accidents*. Note that also *occurrences* to some extent can be investigated by the same approach.

The classification of *incidents* and *accidents* is carried out in a top-down fashion, following the steps below:

- First, an incident/accident is classified into one of the eight I/A categories given in **Section 2.3**. If the deviation is an incident, the I/A category is not always easy to identify, but it will be classified according to the anticipated course of events, *if* the incident had actually developed into an accident.

- In the frequency model (cf. Figure 2.2) the relevant *main cause(s)* of the I/A event are "ticked off", i.e. "Aircraft technical dependability", "Aircraft operations dependability" and/or "Other conditions". Note that *several* causes can be allocated to an accident/incident.
- In the consequence model (cf.Figure 2.3) those *consequence categories* which are considered to have the highest effect on the no. of fatalities in an accident are "ticked off" (i.e., those factors that could reduce the consequences of the accident if it had a better state).
- For each *main cause* and *consequence* category, the contributing *RIF*s at the *operational* level are ticked off.
- This is carried out also for the *organizational* level and the *regulatory & customer related* level, if it is possible to identify contributing factors at these levels with an adequate degree of certainty.

Furthermore, the *arrows* between boxes are marked to illustrate the contribution of *RIF*s to the frequency and consequence of the incident/accident. When several accidents and incidents are analysed and classified in this way, patterns will occur in the diagram, and arrows that are often marked may be visualised by drawing them thicker. Hence, thick arrows will represent a strong contribution and thin arrows a less strong contribution. Figure 2.2 shows the initial model for accident frequency with all arrows equal in size, indicating equal *contributions* of the *RIF*s.

Figure 2.4 shows the resulting pattern based on the analysis of a number of accidents (cf. **Appendix D5**). Observe that only the *main causes* and the RIFs at the *operational* level are included here.

Figure 2.4 gives us a quick and simple way of illustrating the most important casual relationships. Following the arrows in a top-bottom fashion, we can see that the *Aircraft technical dependability* is the most significant contributor (44%) to the frequency of accidents (because it is registered as a cause in 44% of the accident reports). Furthermore, at the next level the RIF *Design and continuos airworthiness* is the most important contributing factor (30%), and so forth.

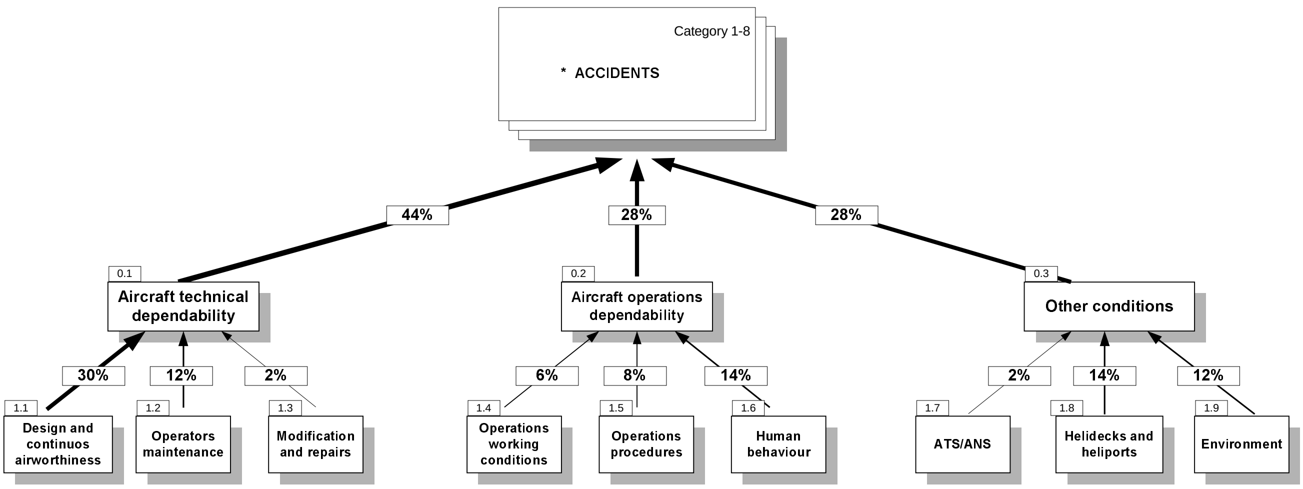

Figure 2.4 Result of accident analyses. The RIF (Level 0 and Level 1) contributions to accident frequency.

2.8 Risk quantification

2.8.1 Notation

In the quantification of risk the following notation apply

Risk influencing factor, *RIFx.y*
= The *RIF* no. *y* at level *x* (*x* = 1, 2, 3).

In particular, the *RIF*1.y represent the *operational RIF*s. There are 9 operational RIFs for frequency (Figure 2.2), and e.g. *RIF*1.1 = *Design and continuous airworthiness*. Similarly there are 14 operational *RIF*s for consequence (Figure 2.3).

Considering the operational *RIF*s for *frequency* (i.e. *RIF*1.*y*, *y* = 1, 2, … 9), the following notation applies:

Status of *RIFx.y* = *Status*(*x.y*)
= Probability that the *RIFx.y* is observed to have a "bad state" during one flight hour
= Probability that a *deviation* caused by *RIFx.y* has occurred during a flight hour.

Weight ("strength") of *RIFx.y* in an I/A of type *j* = $W_j(x.y)$
= Probability that an accident of category *j* occurs, *given* that *RIFx.y* has a "bad state".

Contribution of *RIFx.y* to an *accident* of I/A type *j* = $Contrib_j(x.y) = W_j(x.y) \cdot Status(x.y)$
= Probability that an *accident* of category *j* caused by *RIFx.y* occurs during one flight hour
(Number of accidents of category *j* being caused by *RIFx.y*, divided by number of flight hrs).

2.8.2 Break down of risk

The risk, *R*, of an activity is *quantified* as

$$R = f \times C$$

where
f = *accident frequency*, i.e. mean number of accidents per million person flight hour
C = *accident consequence*, i.e. the mean number of fatalities per *accident*

The accidents of helicopter traffic is in the present study split into 8 I/A - categories (see **Section 2.3**), and it is required to assess the contribution to the risk from each of these 8 I/A categories. Thus, we introduce

$f_j = f$ (I/A j) = Accident frequency for I/A-category no. *j*; *j* = 1, 2, … 8
$C_j = C$(I/A j) = Accident consequence for I/A-category no. *j*; *j* = 1, 2, … 8

Here f_j is estimated as *number of accidents of category j*, divided by the *number of person flight hour*s, and C_j is estimated as *number of fatalities (in accidents of category j)*, divided by *number of accidents of category j.*

The total risk for all eight I/A - categories equals

$$R = f(\text{I/A } 1) x C(\text{I/A } 1) + f(\text{I/A } 2) x C(\text{I/A } 2) + \ldots + f(\text{I/A } 8) x C(\text{I/A } 8)$$

That is, we write

$$R = f_1 \cdot C_1 + f_2 \cdot C_2 + \ldots + f_8 \cdot C_8$$

In this notation, the total accident frequency equals

$$f = f_1 + f_2 + \ldots + f_8$$

and the *average consequence* in an accident (when the I/A category is not specified) equals

$$\mathrm{C} = (f_1 \cdot C_1 + f_2 \cdot C_2 + \ldots + f_8 \cdot C_8) / f$$

Thus, we also have (as stated above)

$$R = f \cdot C$$

Below, a model will be established to relate each of the above frequencies, f_j and consequences, C_j to the *status* and *weight("strength")* of the *risk influencing factors*. In **Section 2.9** we present the model for the accident *frequencies and* accident *consequences*. There will be a focus on how the effect of the *operational RIF*s is modelled.

2.8.3 Risk measures

In this Report, the risk is mainly quantified as

FMPH = number of fatalities per million person flight hours.

FMPH can be obtained as the product of accident *frequency* (number of accidents per million person flight hrs) and accident *consequence* (number of fatalities per accident).

This risk measure also directly provides the *FAR* value

FAR = number of fatalities per 100 million person flight hours = FMPH · 100.

Both these two measures are convenient as they are in widespread use, and can be used for comparison of the risk for various kinds of activities. For the passengers (essentially platform work force) the helicopter flight time is considered as part of their working hours. Thus, the *FAR* value for their helicopter flight hours could be compared with the *FAR* value for their hours on the platforms (and be combined to give an overall weighted *FAR* for the total working time). Further, *FAR* was the risk measure used in the previous study HSS-1.

An alternative risk measure in common use for *transport* is

FKM = number of fatalities per billion person flight km.

This is in particular relevant when a certain transport work shall be carried out, and one shall compare different means of *transport*. This is not a main issue in the present study.

Some I/A categories are related to take off and landing. In particular for these accidents the risk could be given as

FPF = number of fatalities per million person flights.

In total, the overall judgement is that *FMPH* (or equivalently *FAR*) is the most appropriate risk measure for passengers of offshore helicopters. However, it should be noted that if the number of flights per person flight hours changes during a time period (e.g. due to increased/reduced use of shuttling), this will imply that the (relative) accident frequency and risk for I/A 1: *Heliport* and I/A 2: *Helideck* will also change.

For the helicopter crew, very much the same argument applies. It is the risk per hour in the helicopter that is most relevant; thus *FMPH* or *FAR* should be used. However, it should be noted that for crew obviously training and SAR operations should be included, which would give a different (higher) risk figure than the one presented in this report. For crew an alternative risk measure could be the *individual risk*:

IR = Probability to be killed (by helicopter accident) in one year

which is obtained from *FMPH* (or *FAR*), in combination with the number of helicopter hours per year of a crew member.

A helicopter operator (or helicopter manufacturer) would use e.g.

FHF = Number of accidents per million helicopter flight hours.

An oil company using the helicopter service could use the measure

PLL = Probability for Loss of Life = Number of fatalities per year for this activity.

Thus, *PLL* gives a measure for the total risk of the activity (as helicopter *transport*). This is the best measure for cost-benefit considerations, and would for instance also demonstrate the benefit of reducing manning of risky activities (here reduce number of person flight hours).

2.8.4 The risk assessment approach

A method for assessing the risk of the helicopter traffic at a given instant in time is established by the following four steps:

1. The average accident frequency, accident consequence and risk for the period 1990-1998 is assessed, based on statistical data; see **Section 3.1.**
2. Models for accident frequency, f_j and accident consequence, C_j are established to demonstrate how these parameters depend on the *RIF*s (without quantifying the relationships); see **Section 2.9.**
3. Expert judgements and data are used to estimate the strength of the relationships between the various *RIF*s and accident frequency and consequence. Then the full quantification model is established; see **Sections 3.2** and **3.3**.

4. *Changes* in the status of *RIF*s over the period 1990-1998 are assessed. In combination with the model this information can be used to provide e.g. risk estimates for 1990 and 1998 respectively; see **Section 3.6**.

To formalise, let

$\overline{R} = Average\ risk\ \ over\ 1990 - 1998$ (estimated from statistical data)
$R_{90} = Risk\ in 1990$ (estimated from $\overline{R}$ *and* expert judgements/risk model)
$R_{98} = Risk\ in 1998$ (estimated from $\overline{R}$ *and* expert judgements/risk model)

These quantities are illustrated in **Figure 2.5**. Observe that $\overline{R} = (R_{90} + R_{98})/2$.

Further, when the model is established, it can also be used to predict the *future* risk, *given* specific future changes in the *RIF*s.

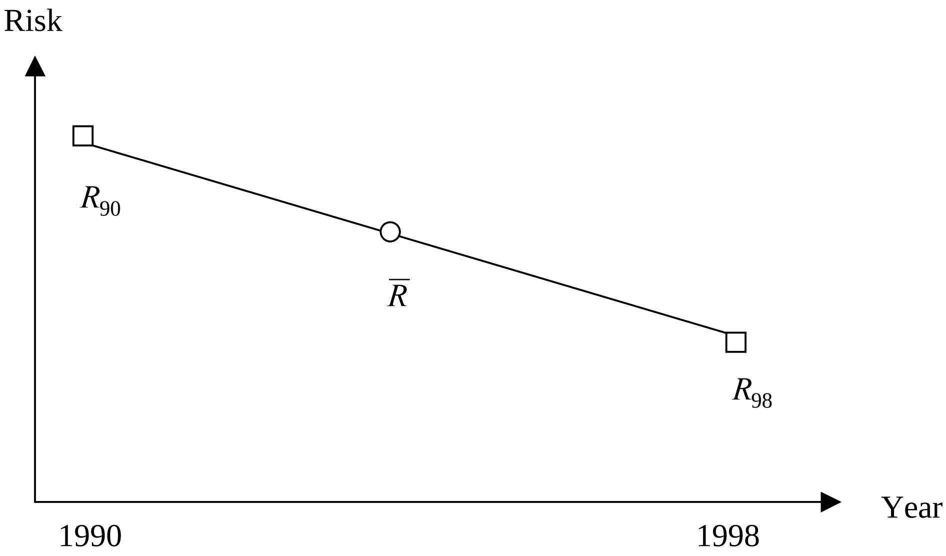

Figure 2.5 Illustration of risk concepts (average risk and risk of specific years).

2.9 Effect of *RIF*s on the risk

2.9.1 Effect of operational *RIF*s on the accident frequency

This section describes how the effect of the *operational RIF*s on the I/A frequency is modelled. (Observe that at present we ignore the intermediate Level 0 "Main causes" in Figure 2.2). Thus, in the quantification model the nine operational *RIF*s for frequency are connected *directly* to the I/A-event, see **Figure 2.6**.

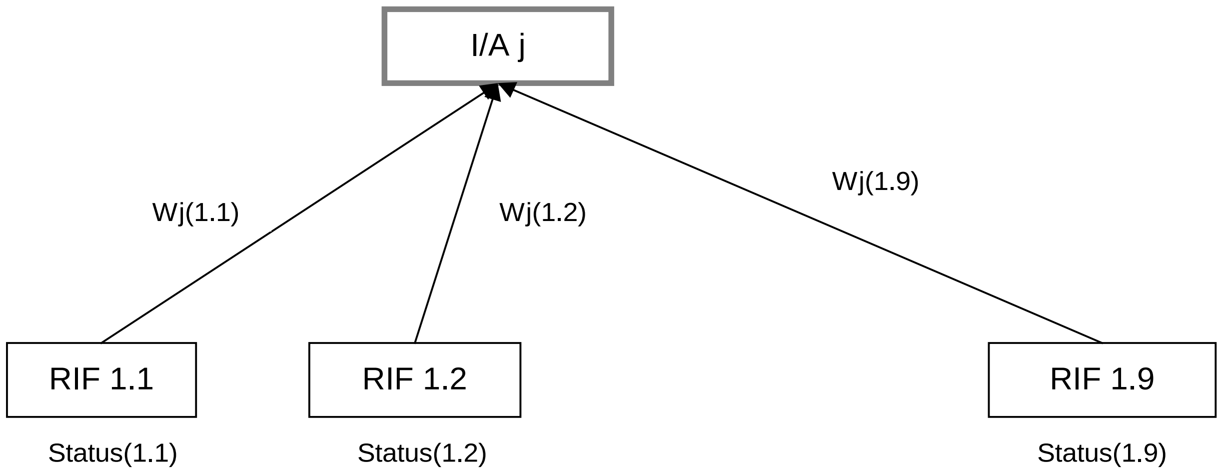

Figure 2.6 Weights and statuses of operational RIFs for frequency

In the quantification model we first split the frequency, f_j of accidents of I/A category no. *j* (I/A j) into contributions from the various operational *RIF*s. As the operational RIFs are defined to the RIFs at level 1, it follows from the notation introduced in Section 2.8.1 that we write

(2.1) $f_j = f\,(\text{I/A j}) = Contrib_j(1.1) + Contrib_j(1.2) + \ldots. + Contrib_j(1.9)$

Thus, the *contribution* of a *RIF* directly tells how much it contributes to the frequency of the I/A category in question. The actual accident data (in combination with expert judgements) are used to perform such a splitting of the various failure frequencies.

The model (2.1) is further detailed by introducing both the *status* (i.e. good or bad state) and the *weight* (or *strength/importance*) of the 9 operational *RIF*s. The *status* of the *RIF* could be seen as a quantification of the *boxes* in Figure 2.2, and it will be quantified *independently* of the I/A category:

Status(1.*y*) = Status of *RIF* 1.*y* (*y* = 1, 2, … 9)

It is given the following interpretation:

Status(1.*y*) = Probability that *RIF* 1.*y* is observed to have a "bad state" during one flight hour
= Probability that a *deviation* caused by *RIF* 1.*y* has occurred during a flight hour.

The *weight* of a *RIF* tells how likely it is that a "bad state" results in an *accident* of the given type. It can be seen as the quantification of the *arrow* from a *RIF* to the accident of the relevant I/A category. Note that *different weights* can be given to the various I/A categories, and the following notation apply:

$W_j(1.y)$ = Weight of *RIF* 1.y in I/A category no. *j*; *j* = 1, 2, …. 8; *y* = 1, 2, … 9.

The weights are defined as:

$W_j(1.y)$ = Probability that an accident of category *j* occurs, *given* that *RIF* 1.*y* has a "bad state".

Thus $W_j(1.y)$ gives the fraction of deviations of I/A category j, that actually leads to an accident.

To summarize:

- The *status* will measure to what extent a *RIF* has a "bad state".
- The *weight* will measure the *effect/importance* of having a "bad" state", i.e. how likely it is that a "bad state" results in an accident; (or the *weight* gives the "*strength*" of the influence of the *RIF*).

Observe that the *weights,* are often expected to be *fixed* in time, i.e. they are *not* changed when operational conditions are changed or risk reducing measures are introduced. So, risk-reducing measures are mainly expected to improve the *status* of a *RIF*.

From the above definitions of $Status(1.y)$ and $W_j(1.y)$ it follows that

(2.2) $$Contrib_j(1.y) = W_j(1.y) \cdot Status(1.y)$$

By summing over all I/A categories we get the "total contribution" of such a *RIF*. That is, the *total* contribution to the occurrence of accidents by *RIF* 1.*y* for frequency equals

$$TotContrib(1.y) = Contrib_1(1.y) + Contrib_2(1.y) + \ldots + Contrib_8(1.y)$$

These total contributions can be used for *ranking* the 9 risk influencing factors for frequency according to their overall impact on accident frequency. This is rather similar to what was done in HSS-1. However, there are some benefits of further factoring out the *contribution* into the *weight* and *status*:

- Utilise the *incident* (and *occurrence*) data in a more direct and natural way
- Separate the characterisation of the *RIF* that is common to all I/A categories (i.e. *statuses*) and the characterisation that is I/A specific (i.e. *weights*)
- Values of both *weights* and *statuses* will be more informative than just providing their products (i.e. *contributions*).
- In some cases experts that are consulted might feel more comfortable in estimating *weights* and *statuses* (rather than contributions).
- Usually a significant amount of data will be available to estimate the *statuses* (using deviation reports). Thus, expert judgements are most urgently required in estimating the *weights.*

It is stressed that it is *possible* to apply the model, *without* factoring out the *contributions* into *weights* and *statuses*. For some *contributions* one might actually choose *not* to carry out the factorisation (e.g. depending on what level of detail the experts feel most comfortable).

2.9.2 Model for accident consequences

The model for accident consequences is somewhat different from that of accident frequency. Accident data/reports provide very scarce information on the 14 operational RIFs for consequence, and it is also rather challenging to obtain such information through expert judgements.

However, an expert judgement session has been carried out, asking for the following information. For each I/A category the experts were asked to judge whether the operational RIF for consequence has Zero (0), Low (L), Medium (M) or High (H) importance, where:

0 = This *RIF* is assumed to have no effect.

L = It is *possible* that the status of this *RIF* will have a *certain* effect on the number of fatalities, given that an accident of this category has occurred

M = It is *likely* that the status of this *RIF* will have a *certain* effect on the number of fatalities, given that an accident of this category has occurred

H = It is *likely* that the status of this *RIF* will have a *considerable* effect on the number of fatalities, given that an accident of this category has occurred

Combining these judgments we get for each I/A category a "score" of the 14 operational *RIF*s for consequence, see Section 3.3.

These scores are used to quantify the expected change in a C_j, when we are given predicted changes in status of the 14 operational *RIF*s. Main steps of this approach are as follows:

- For I/A category no. j we start from the *average* consequences, C_j for the period 1990-98 (say for 1994)
- The estimated consequences at another time instant are modified, taking into account the estimated change in the operational RIFs.
- The change in consequence due to an operational RIF is proportional both to the score and to the predicted change in status of the RIF
- The effect of all 14 operational RIFs are assumed independent.

2.9.3 Effect of other *RIF*s

Only the effects of the *Operational RIFs* have been discussed in the quantitative modelling. First, we have skipped Level 0 "Main causes" (see Figure 2.2), i.e.:

0.1 Aircraft technical dependability
0.2 Aircraft operations dependability
0.3 Other conditions (i.e. conditions external to aircraft).

Likewise, the similar grouping at the top level of the consequence influence model has been skipped (see Figure 2.3). Observe that the first mentioned "causes" *could* also be seen as a "grouping" of the operational *RIF*s at the level below, thus representing "super *RIF*s". Thus, weights and statuses of these three "super *RIF*s" could be obtained as described in **Sections 2.8.1** and **2.8.2**, but now with three *RIF*s instead of 9 (14). There will however be a problem that the *status* no longer is independent of the I/A category, making the modelling more complex. Therefore, this level of the influence diagram is here merely included for illustration purposes, and will *not* be included in the *quantitative* model.

The *Organizational RIF*s and the *Regulatory and customer related RIF*s are not included in the quantitative model. They are included in the influence diagram to show the overall influences, and to demonstrate possible ways to change the operational *RIF*s.

So, the effect of the *Organizational RIF*s is to change the *status* of the *Operational RIF*s. Thus, to each "arrow" from an organizational to an operational *RIF* we could associate a "score", indicating the strength of the influence from the organizational to the operational factor, see Section 3.4. However, as stated above, the organizational *RIF*s are essentially used in the qualitative analysis.

2.10 The use of expert judgements.

Expert judgements are used to estimate contributions (weights and statuses) of RIFs. Further, expert judgements are required to quantify changes in RIFs for the time periods 1990-1998 and 1998-2008, respectively. Use of such expert judgements requires that the sessions or workshops be carried out according to specific rules, in order to ensure credibility of the results.

A lot of literature exists on the use of expert judgements, e.g. see references given in [Øien et al, 1998], [Hokstad et al, 1998] and [Rosness, 1999]. The *Expert judgement handbook*, [Øien et al, 1998] and [Hokstad et al, 1998] recommends a rather simple approach to expert judgements in cases like the HSS-2 study. This is because there are no major controversies involved, and the experts can be trusted to provide their best and honest judgement without bias due to specific interests. Other main recommendations provided in these publications are listed below:

- The experts should together cover all main aspects of the problem area
- Objectivity of the experts is mainly ensured through the process of selecting the experts, i.e. by excluding any person with a 'personal' interest in the matter
- Keep questions simple
- Allow for follow-up questions, and include qualitative questions to get the most knowledge from the experts
- Obtain estimates at the level of resolution which is most appropriate for the expert (e.g. technical deviations are discussed relative to a suitable technical break-down of the helicopter)
- Start the elicitation by questioning the experts independently (recording individual judgements), and include group sessions to discuss discrepancies.

Thus, in the rather simple approach used in the present study, no attempt has been made to evaluate the various experts, in order to give their judgements different weights. Rather, consensus has been obtained in a final group session. Such a group session is very useful in order to clear up misunderstandings, or rather different interpretations of concepts introduced in the study (like the precise definition of the RIFs). Of course such an approach of reaching consensus requires that everybody speak out his or her own opinion, and that no one tries to dominate the meeting. This can be controlled by interference of session leaders, and by obtaining individual judgements prior to the group session. Actually, these types of problems were essentially not encountered in the present study.

2.11 Data sources and uncertainties

Relevant data sources for operational and accident/incident data are:

- The Civil Aviation Authority, Norway (NCAA)
- The Aircraft Accident Investigation Board, Norway (AAIB / N)
- The British Civil Aviation Administration (CAA - UK)

- The British Aircraft Accident Investigation Branch (AAIB / UK)
- Helikopter Service A/S (HS)
- Norsk Helikopter A/S (NOR)

These are the main sources used for quantifying the (statistical) risk level; see discussion in **Appendix B**, Section B.3.

Further, the following data sources have been used:

Accident and Incident Reports
In total 14 accident reports and 15 incident reports have been available to the project. These reports have been used to identify (probable) contributions of various RIFs to the occurrence of each accident or incident. The analyses are summarized in **Appendix C**. However, as pointed out in **Chapter 1.4**, the aviation authorities in Norway and UK to some extent are using different criteria when classifying accidents, serious incidents and incidents. Hence, when analysing the reports we had to exercise our own judgement.

Deviation Reports
More than 800 deviation reports from the Norwegian *Sector* have been available (see **Appendix C**). These are used to obtain the number of deviations within various categories as *operational*, *technical*, etc. A similar number of British occurrences have been analysed, giving the fraction of *technical*, *operational* and *other* occurrences during the various phases of a flight (i.e. take off, hover, climb, cruise, etc).

Expert judgements and work shops
Various work shops / expert judgement sessions have been organized to obtain expert opinions regarding risk influencing factors and risk related changes in the relevant time periods (see **Appendix D** for details):

- Workshop regarding changes in the British *Sector* (executed by Cranfield University)
- Workshop regarding changes in the Norwegian *Sector*
- Workshop on RIFs regarding *Technical dependability* for accident frequency
- Workshop on RIFs regarding *Operations dependability* and *Other conditions* for accident frequency
- Summarizing work shop

Questionnaires
Questionnaires have been used as a supplement to expert judgements, in particular to obtain opinions concerning the RIFs for consequence (see **Appendix D**).

Management interviews
The CEOs and the technical and/or operative managers in the following organizations have been interviewed, in addition to representatives of the trade unions, in order to have their views particularly on the RIFs at Level 2 and 3 in the influence diagrams:

- The Norwegian Petroleum Directorate (NPD; Oljedirektoratet)

- The Aeronautical Inspection Division of the Civil Aviation Administration, Norway (CAA-N), *in this Report abbreviated NCAA*[1] (Luftfartstilsynet).
- The Air Traffic Services Section (ATS) of The Civil Aviation Administration, Norway (CAA-N) (Lufttrafikktjenesteseksjonen i Luftfartsverket)
- Helicopter Service A/S (HO; Helicopter Operator)
- Norsk Helikopter A/S (HO; Helicopter Operator)
- The Helicopter Committee of The Norwegian Federation of Trade Unions (LO’s Helikopterutvalg)
- Several of the oil companies (Customers)

Inquiries / reviews
All participants in the project (cf. Chapter 1.2) have been invited to comment on Draft Reports, particularly in order to give supplementary information and correct possible misinterpretations. In addition, some 40 representatives from the seven oil companies, the two Norwegian offshore helicopter operators, the NCAA, NPD and AAIB / N attended a one day, unofficial conference November 24th , 1999, in order to review the project results and discuss the conclusions and recommendations.

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[1] After January 1st , 2000, The Aeronautical Inspection Division (Luftfartsinspeksjonen) will be separated from The Civil Aviation Administration, Norway (CAA-N; Luftfartsverket). The new name of the former is **The Civil Aviation Authority, Norway (NCAA)**; Luftfartstilsynet.

3. PROJECT RESULTS

In this chapter we present the main results of the Helicopter Safety study 2 (HSS-2). First, in **Section 3.1**, the statistical risk level and trends are given. Next, results of the quantitative model are presented, focusing on the importance or effect of the operational RIFs on the risk. The estimated change in the risk during the period 1990-98 is discussed, and predicted changes for the next decade (1998-2008) are presented.

3.1 Statistical risk level of North Sea helicopter traffic

This Section presents the risk level for North Sea helicopter *transport*, based on relevant accident and traffic data, as well as trends during the time period 1990 - 1998. The number of fatalities per million person flight hours is used as measure for the risk level. The analysis includes all offshore helicopter *transport* to and from Norway and UK, and related *transport* between offshore installations (platforms or ships).

The calculated risk only reflects accidents and traffic volume related to crew and passengers. Activities and accidents related to training, search and rescue operations (SAR) are not considered relevant and are not included in the figures. Accidents to “third party” personnel, e.g. helideck personnel, are also excluded. This is because, for the purpose of this report, the risk for such personnel should be considered part of the risk combined with the installation (platform or ship).

First, the overall estimate of the present risk level in the offshore helicopter *transport* is presented. Then the accident and traffic data are summarized. Observed trends in the data are examined in **Section 3.1.4**.

3.1.1 Overall Risk Level

The statistical data of helicopter accidents in the North Sea gives the following basic data for the period 1990-1998 (both years included):

Traffic volume:	≈ 15.7 million person flight hours
Number of accidents:	15
Number of fatalities:	29

(Details are given in **Table 3.1** and **Sections 3.1.2-3.1.3**). These data directly give the following estimates for the period 1990-1998:

Accident *frequency*:		0.96 accidents per million person flight hrs
Accident *consequence*:		1.93 fatalities per accident
Risk:	0.96 x 1.93 =	1.85 fatalities per million person flight hrs; i.e. FAR = 185[19]

Thus, risk is here measured as *Fatalities per million person flight hours.* Alternatively, the Fatal Accident Rate (FAR) gives the number of fatalities per 100 million person flight hours.

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[19] In this Chapter and in other parts of the report we approximate 1.85 with 1.9 to represent the risk level.

In **Table 3.1** and **Table 3.2** separate risk figures are calculated for comparison with the period 1966-1990. This is because the HSS-2 includes risk to pax/crew only (i.e. fatalities outside the helicopter are excluded, as opposed to the HSS-1 study).

Table 3.1 Estimated risk for North Sea helicopter *transport* during 1990 - 1998. (Includes risk to passengers and crew only.)

Sector	Fatalities	Total number of person flight hours	Fatalities per million person flight hours	FAR (Fatalities per 100 million flight hours)
Norway	12	5 241 536	2.3	230
UK	17 (19*)	10 477 845	1.6 (1.8*)	160 (180*)
Total	**29 (31*)**	**15 719 381**	**1.9 (2.0*)**	**190 (200*)**

*) Numbers in parentheses are valid for comparison with the period 1966-1990 only.

3.1.2 Changes in the statistical risk level from the period 1966-90.

The risk level for the time period 1966 – 1990 was estimated by SINTEF in a similar study HSS-1 in 1990 [INGS90][20]. In Table 3.2 the results are presented and compared with the present risk level. As mentioned, accidents involving fatalities of third party personnel (i.e. persons other than passengers and crew) were included in the in the previous study. Two such fatalities occurred in the British *Sector* in the 1990 – 1998 period. For comparison with the HSS-1 results these fatalities *are included* in the figures of Table 3.2.

Table 3.2 Comparison of estimated number of fatalities per million person flight hours for the North Sea helicopter *transport* in the periods 1966 – 1990 and 1990 – 1998.

Sector	Period		Change
	1966 – 1990	1990 – 1998	
Norway	4.1	2.3	- 45%
UK	3.7	1.8*	- 50%
Total	**3.8**	**2.0****	**- 47%**

[20] The HSS-1 considered accident data from start of the petroleum activity until 1990-01-31

**) Values used for comparison with the period 1966-1990.

In the Norwegian *Sector* the estimated reduction in the risk is 45%. The only accident with fatalities in the Norwegian *Sector* during 1990 – 1998 was the “Norne” accident. In the British *Sector* two fatal accidents occurred in the relevant period, although none since 1992. The risk for the British *Sector* is somewhat lower than for the Norwegian *Sector* in both periods. The reason for this has not been investigated. However, there are no indications suggesting that some underlying factors rather than random fluctuations cause the difference. The risk for both sectors combined has been reduced by 47%.

Table 3.3 Sensitivity analysis for risk development; number of fatalities per million person flight hrs for consequtive time intervals, by different ways of splitting the time period 1966 - 1998 (Norwegian and British *Sector* combined).

Period		Change
1966 – 1986	1987 – 1998	
4.6	**1.5 *)**	**- 70%**
Period		**Change**
1966 – 1985	1986 – 1998	
2.9	**3.3 *)**	**+ 15 %**

*) This value is valid for comparison with the previous period (HSS-1). If only risk to pax/crew is considered, the value is slightly less.

Table 3.1 and **Table 3.2** give the best risk level estimate based on accident statistics. However, it should be observed that because the data material is scarce, there will be uncertainties related to the results. In particular, as illustrated in **Table 3.3,** the results are very sensible to changes in the time periods chosen.

The upper part of Table 3.3 illustrates the effect on the risk levels if the two time periods are changed to 1966 – 1986 and 1987 – 1998, respectively; i.e. we include the years 1987 - 1989 in the second period. Compared to Table 3.2 this would give a more favourable picture of the risk development (a reduction of approx. 70%). The reason for this effect is that no fatal accidents occurred in the years 1987 - 1989.

However, the number of fatalities in 1986 was extremely high (45 were killed). So if the year 1986 is included in the last period to make the two time intervals more equal in length, a dramatically different result is obtained for the risk development (see lower part of Table 3.3). By splitting the period 1966-1998 in this way, we get a *higher* risk in the second period than in the first (i.e. there is a risk *increase* of appr. 15%).

There are uncertainties in the data sources, as well, prompting caution when interpreting the results. Particular attention should be drawn to the following limitations:

- The total number of accidents is small, and one single accident could have a significant impact on the results.

- The numbers only include regular passenger traffic. Thus, accidents related to training flights, test flights and SAR operations are excluded.
- The data used to quantify the risk originate from different sources. For some sources the number of passengers carried are inaccurate. Figures from the British *Sector* are somewhat more uncertain than the Norwegian figures.

For further elaboration of the statistical uncertainty, see **Chapter 1.4** and **Appendix B**, Section B.5.

3.1.3 Helicopter Accident Summary

All relevant helicopter accidents recorded during 1990 – 1998 are listed in **Table 3.4**. This gives the number of fatalities, if any, for each accident. It also includes some accidents that for various reasons are actually *not* included in the statistics. Fatalities of these accidents are given in parentheses. In summary, there are a total of 21 accidents. Actually 6 of these are assumed irrelevant to the present study. This leaves us with 15 relevant accidents, in which 3 are fatal accidents with a total of 29 fatalities. These are the figures used to estimate the risk.

Table 3.5 summarizes these statistics giving the number of accidents and fatalities per sector. The number of fatalities for each sector is used to calculate the risk of that sector, while the total number of fatalities is used to calculate the risk for all North Sea activity.

Table 3.6 gives the distribution of the fatalities and accidents recorded according to the eight incident/accident (I/A) categories used in this study. **Figure 3.1** gives a graphical presentation of the same.

As can be seen from Table 3.6 and Figure 3.1 the most important I/A categories, when judged from the historical data, are:

I/A 3: *System failure during flight*,
I/A 5: *Collision with terrain, sea or building structure*, and
I/A 2: *I/A by take-off or landing on helideck.*

However, it should be observed that the great importance of I/A5: *Collision with terrain, sea or building structure* is due to one single accident with no less than 11 fatalities (the Cormorant accident 1992-03-14). It could be argued that this accident just as well might have been classified in the category I/A 2: *I/A by take-off or landing on helideck*, due to the chain of events. The choice of the I/A 5 category in this case is based on our interpretation of the conclusions in the official Accident Investigation Report, combined with our definition of this category (see **Section 2.3**).

Furthermore, it is interesting to observe that no mid-air collisions (MAC) have occurred, although there have been several *incidents* of this type. The consequences of mid-air collisions are expected to be major, suggesting an additional focus on this I/A category.

Table 3.4 Accidents recorded during 1990 – 1998. Numbers in parenthesis are not included in the risk calculations (see footnotes).

Date	Location		Fatalities				Survivors
			Crew	Passengers	Other	Total	
1990-01-17	N	Statfjord B	-	-	-	-	-
1990-05-06 [1)]	UK	Aberdeen	-	-	-	-	-
1990-07-25	UK	Brent Spar	2	4	-	6	7
1990-08-16	N	Sola	-	-	-	-	-
1990-10-03 [2)]	N	(SAR-oper.)	(5)	-	-	(5)	-
1990-12-24 [1)]	UK		-	-	-	-	-
1991-06-30 [3)]	UK	Tiree	-	-	-	-	-
1991-08-10 [4)]	N	Ekofisk	(3)	-	-	(3)	-
1991-10-02 [1)]	UK		-	-	-	-	-
1992-03-14	UK	Cormorant A	1	10	-	11	6
1992-04-18 [5)]	UK	Heather A	-	-	(1)	(1)	-
1992-09-22 [5)]	UK	Viking Bravo	-	-	(1)	(1)	-
1993-04-15 [6)]	UK	Nr Stronsay	-	-	-	-	-
1993-12-19 [1)]	UK	Aberdeen	-	-	-	-	-
1995-01-19	UK	Brae A	-	-	-	-	-
1995-08-18	UK	Claymore	-	-	-	-	-
1996-01-04	UK	Aberdeen	-	-	-	-	-
1996-01-18	N		-	-	-	-	-
1997-06-03	UK	Aberdeen	-	-	-	-	-
1997-09-08	N	Norne	2	10	-	12	0
1998-01-28	UK	North Sea	-	-	-	-	-
Total	**Accidents: 15 (21)**		**5 (13)**	**24**	**(2)**	**29 (39 [7)])**	**13**

1) No accident report or occurrence report has been available for this accident. However, the accident is considered relevant and therefore included in the analysis.

2) The accident occurred on a search and rescue operation. Although the aircraft was an offshore machine the mission being undertaken at the time of the crash was not offshore related and the accident is thus not included in the analysis.

3) It is assumed that the aircraft was not in offshore transport and is thus not included in the analysis.

4) The accident occurred while positioning a reference bar during maintenance work on the flare and is not included in the analysis.

5) The persons killed by these accidents where helideck persons and not passengers or crew. Thus, these accidents are not included in the final figures.

6) The accident occurred when picking up a passenger at a farm. Although the aircraft was an offshore machine the mission being undertaken at the time of the accident was not offshore related and the accident is thus not included in the analysis

7) Since this number includes non-relevant accidents with a total of 8 fatalities the number used in the risk estimation is 29.

Table 3.5 Summary of relevant accidents and fatalities.

Section	Number of accidents	Fatalities		
		Crew	Passengers	Total
Norway	4	2	10	12
UK	11	3	14	17
Total	**15**	**5**	**24**	**29**

Table 3.6 Distribution of fatalities and accidents into I/A categories. (British and Norwegian Sector combined.)

Incident/Accident category (I/A)	Accidents		Fatalities	
	No.	%	No.	%
1. Heliport	2	13	0	0
2. Helideck	3	20	6	21
3. System failure	7	47	12	41
4. Mid-air collision (MAC)	0	0	0	0
5. Collision with terrain etc.	1	7	11	38
6. Personnel inside	0	0	0	0
7. Personnel outside	0	0	0	0
8. Other/unknown	2	13	0	0
Total	**15**	**100**	**29**	**100**

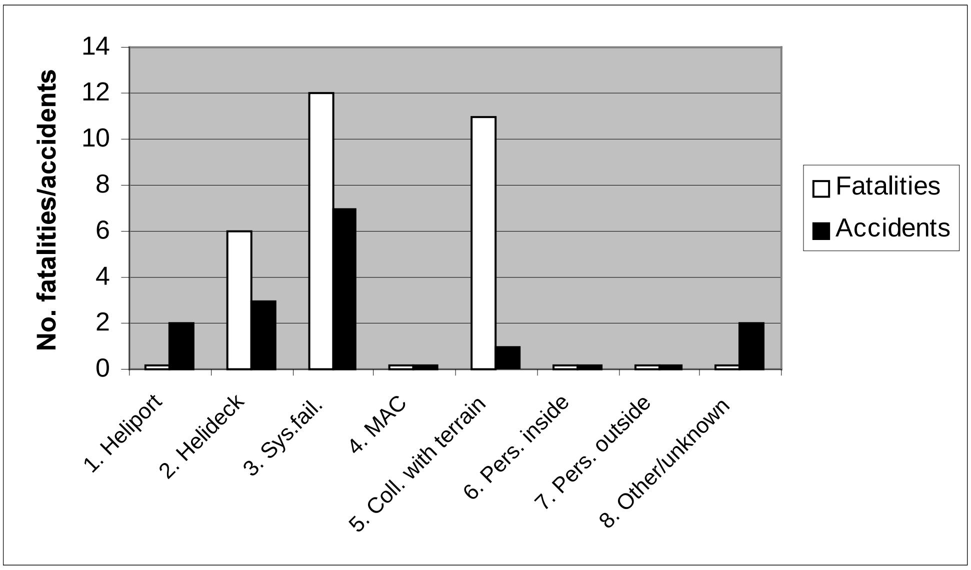

Figure 3.1 Graphical presentation of Table 3.6

3.1.4 Trend analysis

This section focuses on trends in the statistical data of the risk level. Figure 3.2 shows a 5-year *moving average* of the risk from 1973 to 1998. The moving average for a given year is the average number of fatalities per million person flight hours of a five-year period. This means that the first point in the curve is the average risk for the period 1973 – 1977. This point is plotted in the middle of the time interval, i.e. 1975. The data on which the figure is based can be found in **Appendix B** and is for the early years based on [Paulsen, 1995]. This approach is chosen to "smooth" the risk level curve, i.e. to remove some of the statistical fluctuation. From the figure, the risk seems to be generally decreasing in the first period and stabilising around a certain level in the 90's. Also, there seems to be a marked drop around 1981 – 1983 and 1990 –1992. The average risk in the first period is 3.8 fatalities per million person flight hours and 1.9 in the second period (cf. **Table 3.2**).

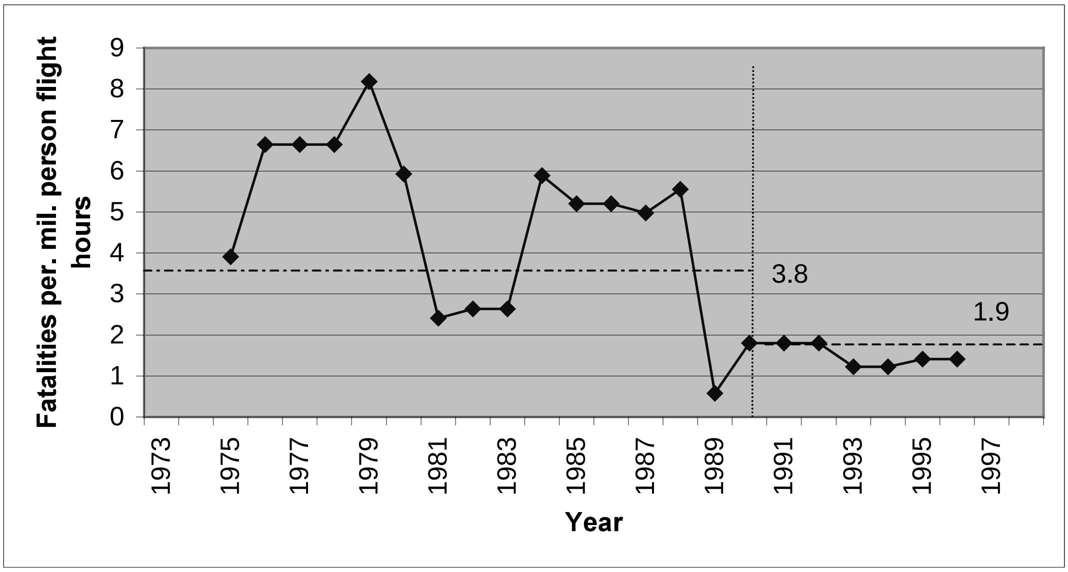

Figure 3.2 5-year moving average of the risk during 1973 – 1998, British and Norwegian Sector combined.

Because the data material for the estimated risk is scarce, we will also examine trends during 1985 - 1998 in terms of the rate of accidents. Although the rate of accidents is not a direct measure of the risk (since there is no consideration of consequences) this will give us some idea of the latest development of the risk level in the North Sea helicopter transport.

Figure 3.3 shows the accident rate per million *aircraft* flight hours during 1985 – 1998 for the British and Norwegian **Sector** smoothed by a 3-year moving average. The value of the moving average for a given year is the average accident rate for the 3-year period with the given year in the middle. For example, the accident rate value for 1990 is calculated as the average accident rate for 1989 – 1991.

Statistics from 1985 – 1989 is included to get a more complete picture of the trend. The data source used is the CAA-UK annual reports for 1985 – 1989 and the data sources described in **Appendix B** for 1990 - 1998. Again we observe a significant drop in the years around 1989 –

1992. Based on this we can conclude that there has been a significant reduction in the number of accidents in the North Sea helicopter transport, when comparing the two periods. Also, using a Poisson model for number of accidents, the reduction is clearly significant at a level of 1%.

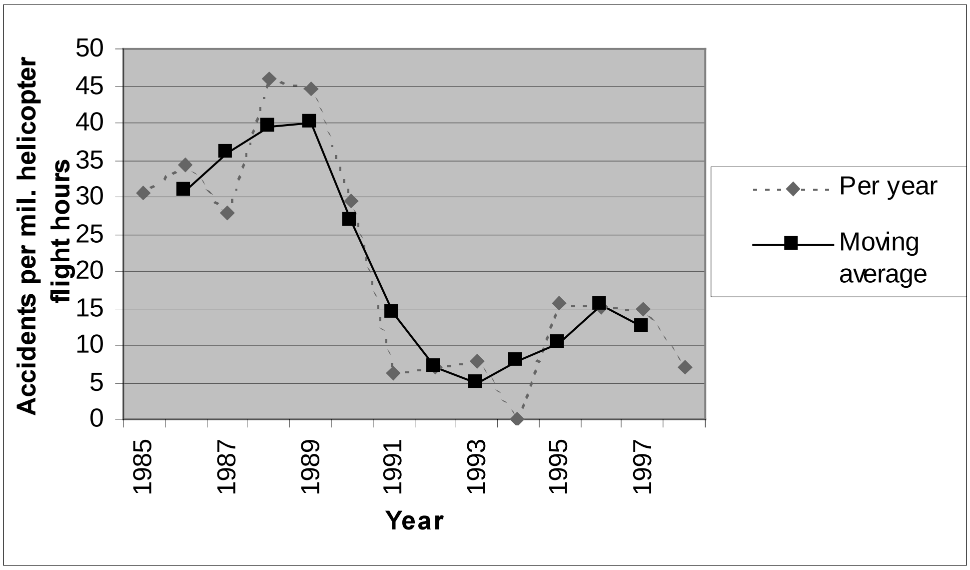

Figure 3.3 Yearly rate and 3-year moving average for the number of accidents per million aircraft flight-hours during 1985 – 1998, British and Norwegian Sector **combined[21].**

3.2 Contributions of operational RIFs to accident frequency

Scope, Sections 3.2 and 3.3

Sections 3.2 and 3.3 together present the main results concerning risk quantification and the effect of the operational RIFs, i.e. Level 1 RIFs, cf figures 2.2 and 2.3.

First in Section 3.2 we consider accident *frequency*. This is split into the accident frequencies of the eight I/A categories. Further, it is demonstrated how the nine operational RIFs for frequency contribute to accident frequency.

In Section 3.3 we take accident consequence into account, and also introduce the 14 operational RIFs for consequence.

Finally in Section 3.3 we also consider the effects of these 9 + 14 operational RIFs on the total *risk.*

Contributions to accident frequency

Table 3.7 presents, in a compact form, the estimated percentual contributions to accident frequency from the nine relevant operational RIFs. For definition of accident see Section 1.5. Appendix D documents how we arrive at the frequency model presented in Table 3.7. The main

[21] Based on all 15 relevant accidents.

results of the frequency model are provided in the margins of the table (i.e. the bottom row and right column).

Table 3.7 Contributions (in %) to accident frequency of the operational RIFs for frequency

RIFs for frequency:	**I/A 1 Heliport**	**I/A 2 Helideck**	**I/A 3 Syst. fail.**	**I/A 4 MAC**	**I/A 5 Coll. terr.**	**I/A 6 P. inside**	**I/A 7 P. outside**	**I/A 8 Other**	**Sum**
RIF1.1 Design	4.9	1.7	19.0	0.0	0.4	0.4	0.8	1.3	28.4
RIF1.2 Maintenance	4.1	1.1	9.7	0.0	0.3	0.3	0.1	0.0	15.6
RIF1.3 Mod./repairs	0.2	0.1	2.0	0.0	0.1	0.1	0.0	0.0	2.4
RIF1.4 Working cond.	0.1	0.2	0.5	0.0	1.9	0.0	0.0	1.0	3.8
RIF1.5 Op. procedures	0.6	6.0	0.0	0.0	1.8	0.0	0.7	1.0	10.0
RIF1.6 Human beh.	0.9	6.6	2.6	0.2	3.0	0.0	1.0	0.5	14.7
RIF1.7 ATS/ANS	0.5	0.0	0.0	0.6	1.3	0.0	0.0	0.0	2.5
RIF1.8 H.deck/H.port	0.0	9.3	0.0	0.2	0.9	0.0	1.1	1.3	12.7
RIF1.9 Environment	1.1	2.0	4.2	0.0	0.9	0.0	1.2	0.5	9.9
Sum	12.4	26.9	38.0	1.0	10.6	0.7	4.8	5.5	100.0

The bottom row of Table 3.7 gives the relative accident frequency of the eight I/A categories. This result is also presented graphically in **Figure 3.4**. This figure reveals that the I/A categories *3: System failure* and *2: Helideck* are the most frequent ones. Together these two categories account for about 65% of the accidents.

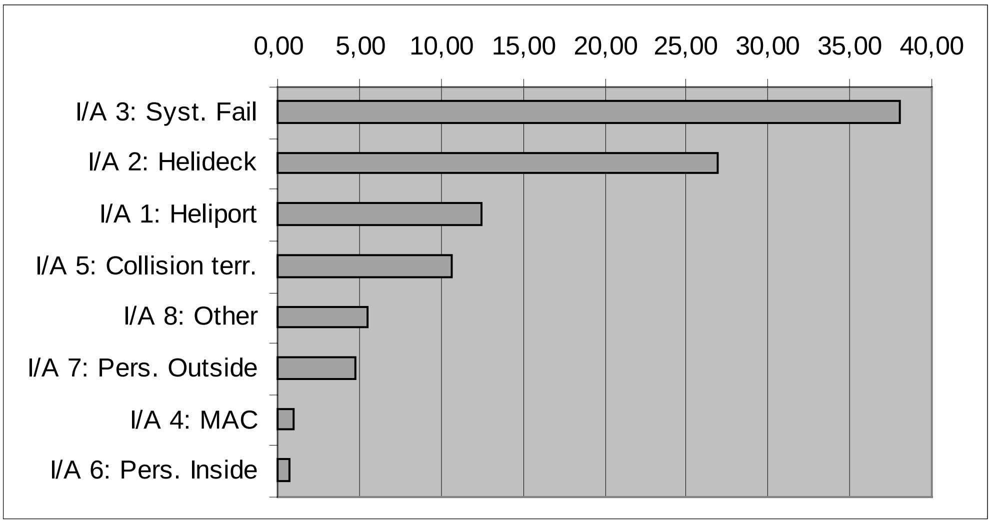

Figure 3.4 Contributions to accident frequency (in %) from the eight I/A categories (cf. column sums of Table 3.7).

The rightmost column of Table 3.7 gives the relative overall contributions of the nine operational RIFs for frequency (when added over all I/A categories). **Figure 3.5** present these results graphically. It is seen that *RIF1.1* *Design and continuos airworthiness* is the major contributor to accident frequency (accounting for 28%).

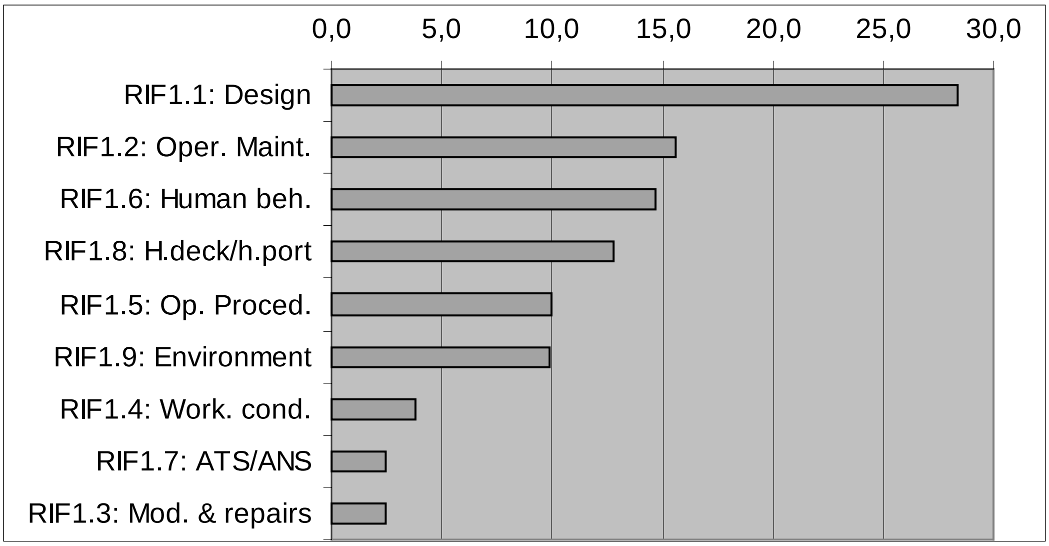

Figure 3.5. Contributions to accident frequency (in %) from operational frequency RIFs (cf. row sums of Table 3.7).

Returning to Table 3.7 it is observed that the majority of the accidents caused by *RIF 1.1 Design and continuos airworthiness* leads to an *I/A 3: System failure during flight*. So this single box in Table 3.7 (with value 19.0) is a major reason why *RIF 1.1 Design and continuos airworthiness* is the major contributor to the accident frequency, and why *I/A 3: System failure during flight* is the most frequent I/A category.

Data sources and approaches

The result summarized in Table 3.7 was established by using various data sources and a combination of two different approaches (1 and 2):

1. A table similar to Table 3.7 was established using deviation reports and expert judgements. A total of about 1000 reported deviations were first categorised in a rather detailed way (see **Appendix C**). This was utilised during an expert judgement session, and the experts were asked how many deviations of a certain category they expected to pass before an accident would be likely to occur. These results were compiled to give a table similar to Table 3.7.

2. Another table similar to Table 3.7 was established from an analysis of 14 accidents for which there was sufficient information available for performing such an analysis. These 14 accidents are identified in Appendix C, and not all of them are "relevant" for the present study (i.e. related to offshore personnel transport). Thus, the distribution of accidents between the eight I/A categories was first modified, to be more like that observed for the 15 *relevant* accidents (which are identified in Table 3.4).

The analysis based on the actual accidents (Approach 2 above) resulted in some cells of the table being empty (as only 14 accidents were analysed). However, the two approaches gave rather similar overall results. The final result, as presented in Table 3.7, was obtained by averaging the results of Approach 1 and Approach 2. In addition, a couple of final adjustments were made by means of a separate expert judgement (see **Appendix D**).

3.3 Risk quantification and the effect of operational RIFs

Scope

In this section we first present estimates for the average consequence of an accident. Combining this with the results on accident frequency given in Section 3.2, we obtain the main quantitative results of the total risk:

1. Estimates for the accident frequency, consequence and total risk for the period 1990-98
2. The risk is split into contributions of the eight I/A categories
3. The contributions of the 9 operational RIFs for frequency to risk (when consequence is fixed) are given
4. The contribution of the 14 operational RIFs for consequence to risk (when frequency is fixed) are given

As previously stated, in addition to relying on accident analyses, all these results utilise expert judgements.

Observe that we do not perform a simultaneous ranking of all the 9 + 14 operational RIFs. The relative importance of the group of 9 RIFs for frequency and the group of 14 RIFs for consequence is rather hard to assess. Thus, the result is considered much more reliable if we focus on separate rankings within these two groups of operational RIFs.
Accident consequences

Table 3.8 summarizes some main results of the HSS-2 study. First, the upper row gives <u>the accident frequencies</u> of the various I/A categories. This result is directly obtained from the accident frequency distribution in the bottom row of Table 3.7, when it is assumed that the total accident frequency equals 0.96 accident per million person flight hours (as obtained from the statistical data presented in Section 3.1.1).

Table 3.8 Main results of model: Accident frequency, consequence and risk of the I/A categories

Parameter	I/A 1 Heliport	I/A 2 Helideck	I/A 3 Syst.fail.	I/A 4 MAC	I/A 5 Coll.terr	I/A 6 P. inside	I/A 7 P.outside	I/A 8 Other	Total All I/A
Frequency (no. of acc. per mill. pers. flight hrs)	0.12	0.26	0.36	0.01	0.10	0.01	0.05	0.05	**0.96**
Consequence (fatalities per accident)	0.1	2.5	2.0	18.0 [1)]	10.0	0.1	0.9	0.2	**2.7**
Risk (fatalities per million person flight hrs)	0.01	0.64	0.73	0.17	1.02	0.00	0.04	0.01	**2.62**

[1)] Accounts for the possibility that a collision involves two helicopters

The second row of Table 3.8 presents the estimated average number of fatalities per accident, i.e. accident consequence. These numbers were provided mainly by expert judgements, as actual fatalities in accidents are observed only for I/A 2: Helideck, I/A 3: System failure during flight and I/A 5: Collision with terrain, sea or building. The given values are based on the assumption that 15 pax and crew are on board the helicopter during the accident. In the rightmost column it is seen that the mean number of fatalities per accident, averaged over all I/A- categories, is equal to 2.7.

The estimated consequences of the I/A categories are presented in **Figure 3.6** as well. These results on accident consequences, combined with the results on accident frequency given in Table 3.7, represent the basis for the risk quantification.

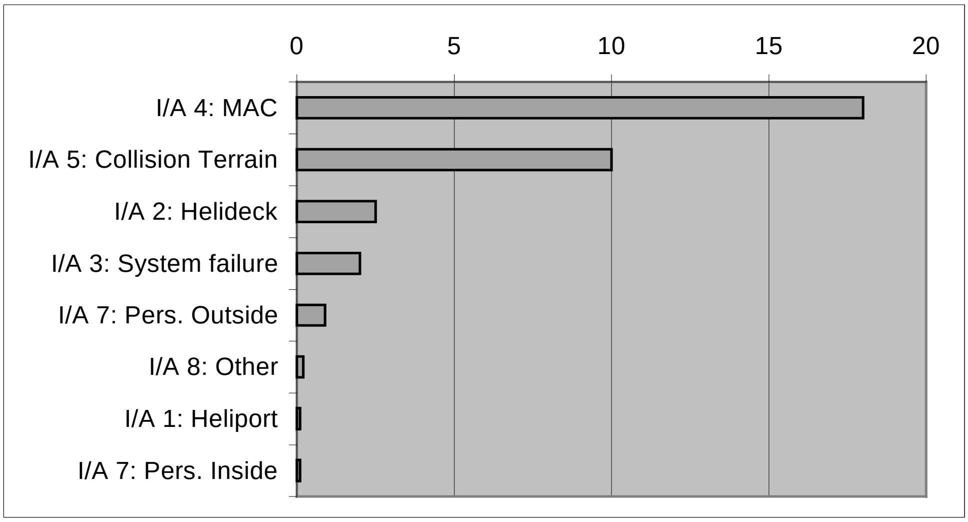

Figure 3.6 Consequence. Average number of fatalities per accident (cf. Table 3.8)

Contributions to risk of the I/A categories

The third row of Table 3.8 gives the contribution to the total risk per I/A category. Multiplying the accident frequency (first row) and the number of fatalities (second row) obtain the numbers. The rightmost column gives the sum over the eight I/A categories.

Observe that the risk obtained in Table 3.8 is not identical to the risk obtained from accident statistics (see Section 3.1 above). The main reason for this is that the number of fatalities per I/A category, estimated at the expert judgement session, gives an overall number of fatalities per accident close to 2.7, rather than the average statistical value 29/15 = 1.9. In particular, the model quantification gives higher estimates for the consequence of the I/A-categories no. 2: Helideck and no. 4: MAC, when compared to the statistical data. In addition, the model gives a somewhat higher frequency for I/A 5: Collision with terrain etc, than do the statistical data. Thus, the distribution of accidents between the I/A categories is not identical for the model and the statistics.

It is difficult to conclude whether this discrepancy in risk values indicates that the previously estimated risk, based entirely on the statistical data, is actually too low (as suggested by the above model calculation, when expert judgements are utilised as well). However, the subsequent discussion will focus on the *relative contributions* to risk, and not the absolute risk values. (The latter were discussed thoroughly in Section 3.1.)

Figure 3.7 presents the last row of Table 3.8. It is seen that *I/A category no. 5: Collision with terrain etc.* contributes most to the total risk, followed by *I/A categories no. 3: System failure during flight* and *no. 2: Helideck.* Similarly, Figure 3.4 gave a ranking of the I/A categories regarding their contributions to accident frequency. By comparing these two figures we see that even if I/A 5: Collision with terrain etc is only ranked number four with respect to accident frequency, it has (as pointed out) the highest contribution to *risk*. The reason is that I/A 5 has rather high consequence, and thus a relatively small contribution to the accident frequency may result in a high contribution to the risk.

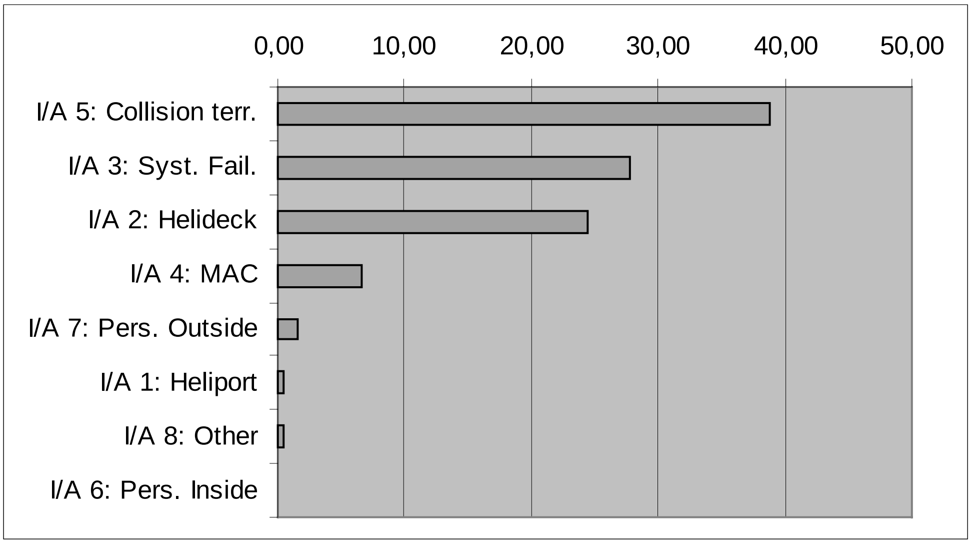

Figure 3.7 Contributions to risk (in %) from the eight I/A categories (cf. Table 3.8).

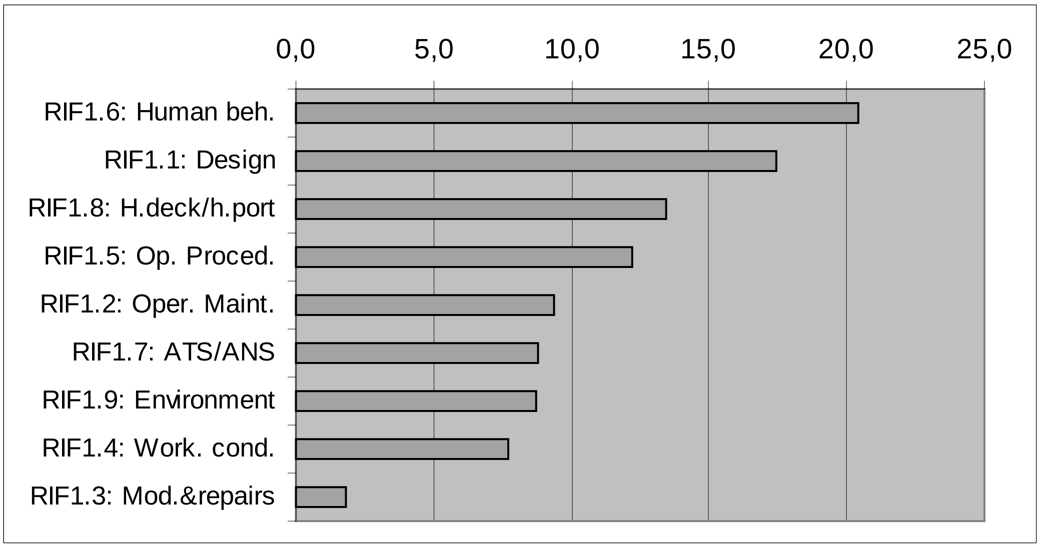

Figure 3.8 Contributions to risk (in %) from the nine operational *RIFs for frequency* (consequences being fixed).

Contributions to risk from the operational RIFs for frequency

Figure 3.5 above provides the contributions to the accident frequency from the nine operational RIFs for frequency. Similarly, **Figure 3.8** presents the contributions to the risk from the same operational RIFs. This new ranking also depends on the consequences of the various I/A categories (cf. Appendix B.5). It actually assumes that the consequences of the I/A categories are *fixed* with the values given in Figure 3.6. So, Figure 3.8 gives the relative contributions to risk in % from the operational RIFs for frequency, assuming the operational RIFs for consequence are fixed.

According to Figure 3.8 *RIF 1.6 Human behaviour* is the major contributor to the risk (20%); remember that RIF1.6 relates to the helicopter crew only. Further, *RIF 1.1 Design and continuos airworthiness* is ranked second with respect to risk. This could be compared to Figure 3.5, which shows that RIF 1.1 is the main contributor to accident frequency.

Ranking of Operational RIFs for consequence

The model for operational RIFs for frequency and the model for operational RIFs for consequence are somewhat different; see Section 2.9. The accident frequency (and then also risk) is actually split into the contributions of the nine operational RIFs for frequency. If all these RIFs reach a perfect state, all contributions vanish, and risk becomes zero. However, the 14 operational RIFs for consequence are used to modify the accident consequence. Thus, the consequence (and risk) will not become zero even if all these RIFs reach the perfect state.

The operational RIFs for consequence are for each I/A category given a score from 0-10. This score is a measure of importance, and indicates to what extent the status of this RIF will effect the number of fatalities, *given* that an accident of this I/A category has occurred. **Table 3.9** presents these scores, which are obtained by expert judgements. Maximum score (10) is given when all eight experts judged this RIF to be of “High” importance with respect to the number of fatalities[22].

[22] Reference is made to Section 2.9.2

Table 3.9 shows that for I/A 4: MAC all scores are either 1 or 2, and the sum of scores for this I/A equals 16, see the bottom-line. Thus, *none* of the RIFs are judged to have a significant effect on I/A 4: MAC. However, both for I/A 2: Helideck, I/A 3: System failure during flight and I/A 5: Collision with terrain etc, there are several RIFs with a significant effect, cf. bottom line of Table 3.9. The scores for the other I/A's are less interesting, as these I/A-s have a rather small contribution to the risk.

The right column of Table 3.9 presents the weighted average of the scores for the various I/A categories. The weights are given according to the contribution of this I/A category to the risk. For instance: Figure 3.7 shows that almost 40% of the risk is caused by *I/A 5: Collision with terrain etc,* and so the scores for this I/A is given a correspondingly high weight. Thus, the total scores, presented in the right column of Table 3.9 provide an overall ranking of the fourteen operational RIFs for consequence *regarding their "ability" to reduce the risk*. The ranking of these RIFs assumes that the accident frequency of all I/A categories are fixed (as in Table 3.8).

Note that the scores somewhat arbitrarily are given values in the range 0-10. Thus, we should focus on *relative* scores (and not absolute values). To emphasise this we may normalise these scores to get the sum 100 instead of the value 87.1 (as found in the rightmost cell of the bottom line of Table 3.9).

Table 3.9 Scores of operational RIFs for consequence (scores ranging from 0-10).

RIFs for consequence:	**I/A 1 Heliport**	**I/A 2 Helideck**	**I/A 3 Syst. fail.**	**I/A 4 MAC**	**I/A 5 Coll. ter.**	**I/A 6 P. inside**	**I/A 7 P.outside**	**Total all I/A**
RIF1.1 Emer. prep. (H/H)	7	7	3	1	5	3	7	4.7
RIF1.2 H/H design	4	8	4	1	3	3	8	4.4
RIF1.3 Emer. equipment	8	8	4	1	5	3	6	5.1
RIF1.4 Impact absorption	9	9	8	1	8	3	0	7.9
RIF1.5 Stability on sea	0	7	10	1	8	6	0	7.7
RIF1.6 Pass. cabin safety	7	7	9	1	8	9	0	7.1
RIF1.7 Survival equipment	2	3	9	1	8	5	0	6.1
RIF1.8 Emer. loc. equipm.	1	1	8	1	6	3	0	4.9
RIF1.9 Crew competence	4	6	8	1	7	10	7	6.6
RIF1.10 Pass. competence	5	6	8	1	6	10	8	6.5
RIF1.11 Emer. procedures	5	6	9	1	7	10	5	6.7
RIF1.12 Emer. prep (SAR)	1	6	9	1	8	4	3	6.9
RIF1.13 Organ.& co-ordin.	1	4	7	2	8	3	3	5.9
RIF1.14 Master environment	1	5	8	2	8	3	2	6.6
Sum, all RIFs	55	83	104	16	95	75	49	87.1

Figure 3.9 presents a ranking of these total scores after normalisation to get the sum equal to 100. Then we could consider Figure 3.9 to give the "contributions" to risk in % of the 14 operational RIFs for consequence. The advantage is that we get a result being analogous to that for the operational RIFs for frequency given in Figure 3.8, and these results are comparable.

One striking feature of the result presented in Figure 3.9 is the small variation between the operational RIFs for consequence**.** The reason for this is that all these RIFs obtain rather high scores for at least some of the I/A categories nos. 2 - 5, which are the most significant ones with respect to risk (c.f. Figure 3.7). However, it is worth noting that the list is topped by three RIFs related to RIF 0.2 Crashworthiness, i.e. the *RIF 1.4 Impact absorption upon hard landing*, *RIF 1.5 Stability on sea* and *RIF 1.6 Pax cabin safety*. Together, these three RIFs account for about 26% of the total scores for consequence. Further, **Figure 3.10** is obtained from Figure 3.9, by grouping the operational RIFs 1.1 - RIF 1.14 into the main categories (RIF 0.1 - RIF 0.4). From Figure 3.10 we see that *RIF 0.2 Crashworthiness* contributes to approximately 39% of the total scores for consequence.

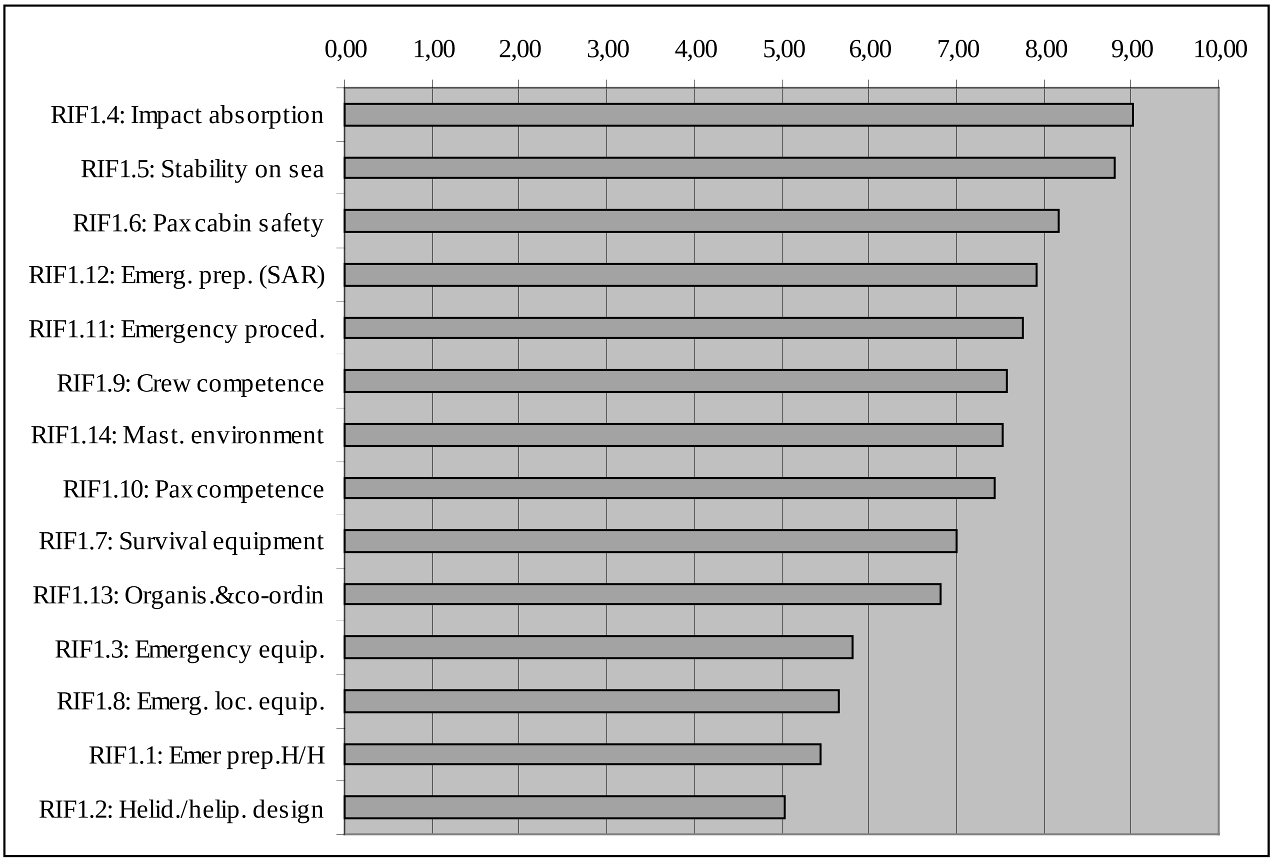

Figure 3.9 "Contributions" to risk of the operational RIFs for *consequence;* frequencies are fixed. (Values are taken from the last column of Table 3.9, but are normalised to give sum 100.)

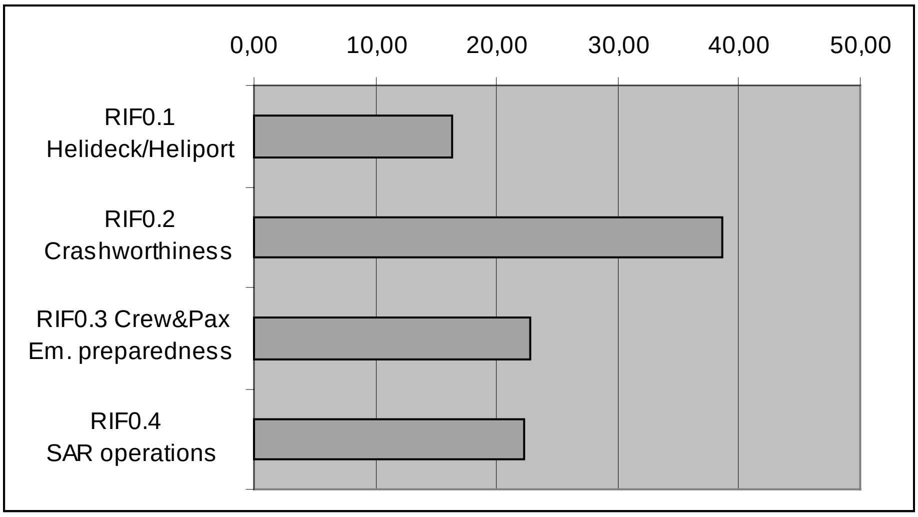

Figure 3.10 "Contributions" to risk of RIF 0.1 - RIF 0.4 for *consequence*; (frequencies fixed). Values are normalised to give sum 100.

Conclusions on the Operational RIFs for frequency and consequence

It is not straightforward to give a reliable comparison of the importance/effect of *frequency* RIFs and *consequence* RIFs; that is, to transform the contents of Table 3.8 and 3.9 into one *single* ranking of the 9 + 14 = 23 operational RIFs. Such an over all comparison would require that we rely on some rather difficult expert judgements (cf. Section 2.9). However, there are two good arguments for paying most attention to improving the status of the operational RIFs for *frequency*:

- A basic principle in Safety Management and risk reduction is to give priority to the frequency reducing measures as opposed to the consequence reducing measures. In other words preventing an accident from happening in the first place is more "profitable" than trying to reduce the consequence. Particularly for air traffic this is considered a good principle, as consequence-reducing measures which are really effective are often hard to find.

- From Figure 3.9, it is seen that there is little difference amongst the consequence RIFs; they are all almost "equally important". Considering the corresponding Figure 3.8 for frequency, it is observed that some of the RIFs are contributing much more than others, and so risk reducing measures related to these RIFs are expected to give more significant effects.

3.4 Effect of organizational RIFs

The influence diagrams of Figures 2.2 and 2.3 illustrate that the *organizational* RIFs will affect the *operational* RIFs and thereby the risk. Expert judgements have been carried out to quantify the strength of these influences, see Figures 3.11 and 3.12.

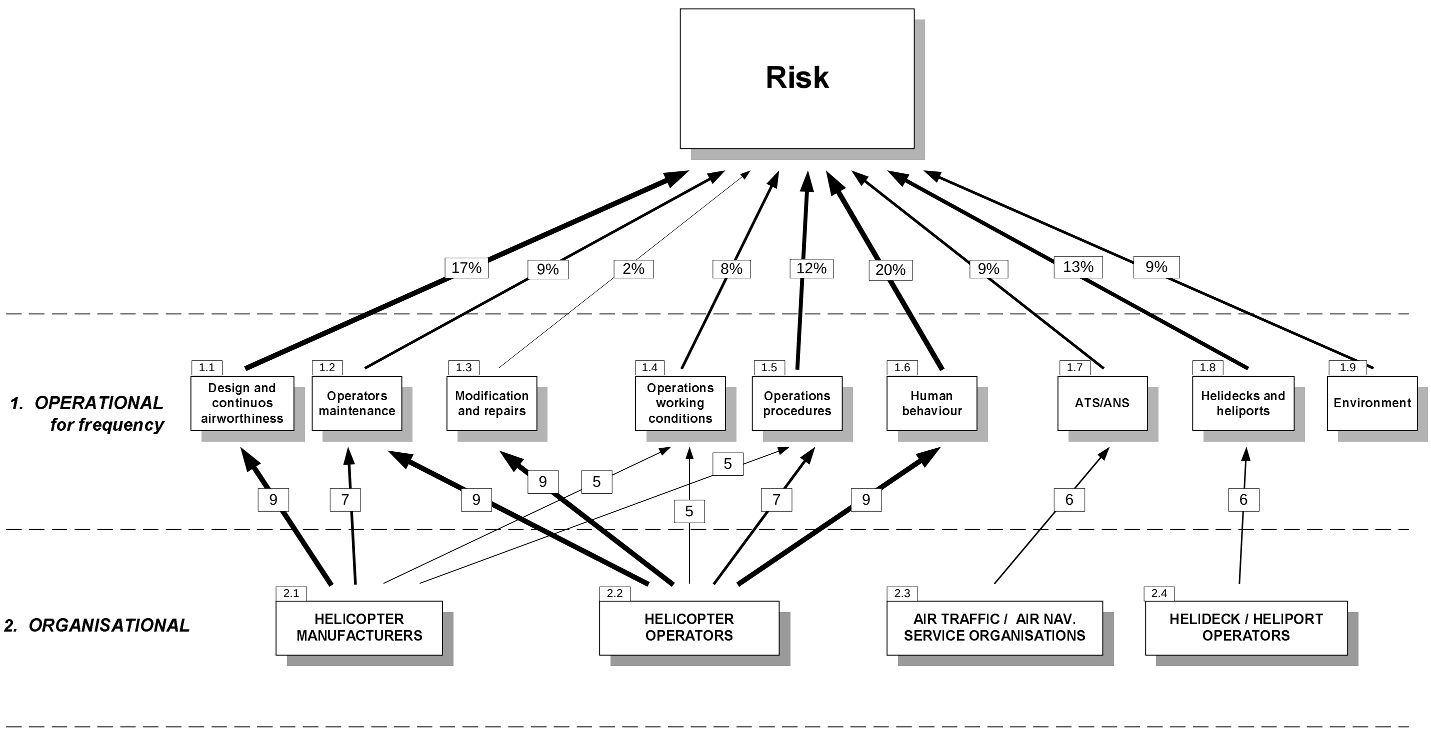

Figure 3.11 Effect of Organizational RIFs on the Operational RIFs for frequency (and on the total risk). RIFs for consequence are fixed.

First, **Figure 3.11** presents

- The *contributions* to risk in % of the nine operational RIFs for frequency (from Figure 3.8)
- The strength of influence (*scores*) that the organizational RIFs (RIF2.1 - RIF2.4) have on the operational RIFs for frequency. These influences are obtained from specific expert judgements and are given values from 1 - 10.

The magnitude of these *contributions* and *scores* are indicated by the thickness of the arrows. When these contributions and scores are combined we obtain an overall picture of the total effect of an organizational RIF. For instance RIF 2.2 Helicopter Manufacturer has a high influence (score) on RIF 1.6 Human behaviour, which at the same time give the highest contribution to accident frequency. This alone points at RIF 2.2 Helicopter Operators as a significant organizational RIF for affecting accident frequency (and risk).

Also considering e.g. its effect on RIF 1.2 Operators maintenance, and RIF 1.5 Operations procedures, it may be concluded that RIF 2.2 Helicopter operators is the organizational RIF for frequency that is has the highest effect on accident frequency. An overall importance measure for this effect is obtained by multiplying a score with the corresponding contribution and sum over all operational RIFs affected:

Overall "importance" of RIF 2.2 Helicopter operator equals

$$9 \cdot 9\% + 9 \cdot 2\% + 5 \cdot 8\% + 7 \cdot 12\% + 9 \cdot 20\% = 4.0$$

Similarly, the overall importance measure for RIF 2.1 Helicopter manufacturer is calculated to 3.2, which to a large extent is attributed to the effect on RIF 1.1 Design and continuos airworthiness. The corresponding results for RIF 2.3 ATS/ANS service organizations is 0.5, and for RIF 2.4 Helideck/Heliport operators equals 0.8. So *Helicopter operator* and *Helicopter manufacturer* are the most important organizational RIFs with respect to affecting risk through reduction of accident frequency (a result which is very obvious just from looking at Figure 3.11).

Figure 3.12 presents the analogous result on how the organizational RIFs affect the operational RIFs for consequence and thus risk, by giving:

- The "*contributions"* in % to risk of the 14 operational RIFs for consequence (from Figure 3.9).
- The strength of influence (*scores*) that the organizational RIFs have on the operational RIFs for consequence. These influences are obtained from specific expert judgements and are given values from 1 - 10.

For instance observe that RIF 2.2 Helicopter Manufacturer has a high influence (score) both with respect to the effect on RIF 1.4 Impact absorption, RIF 1.5 Stability on sea and RIF 1.6 Passenger cabin safety. At the same time, these three operational RIFs are those with the highest "contribution" to risk. This again points at *Helicopter manufacturer* to be an important operational RIF (through its effect on consequence). Looking at Figure 3.12, the same statement is obviously true concerning *Helicopter Operator*.

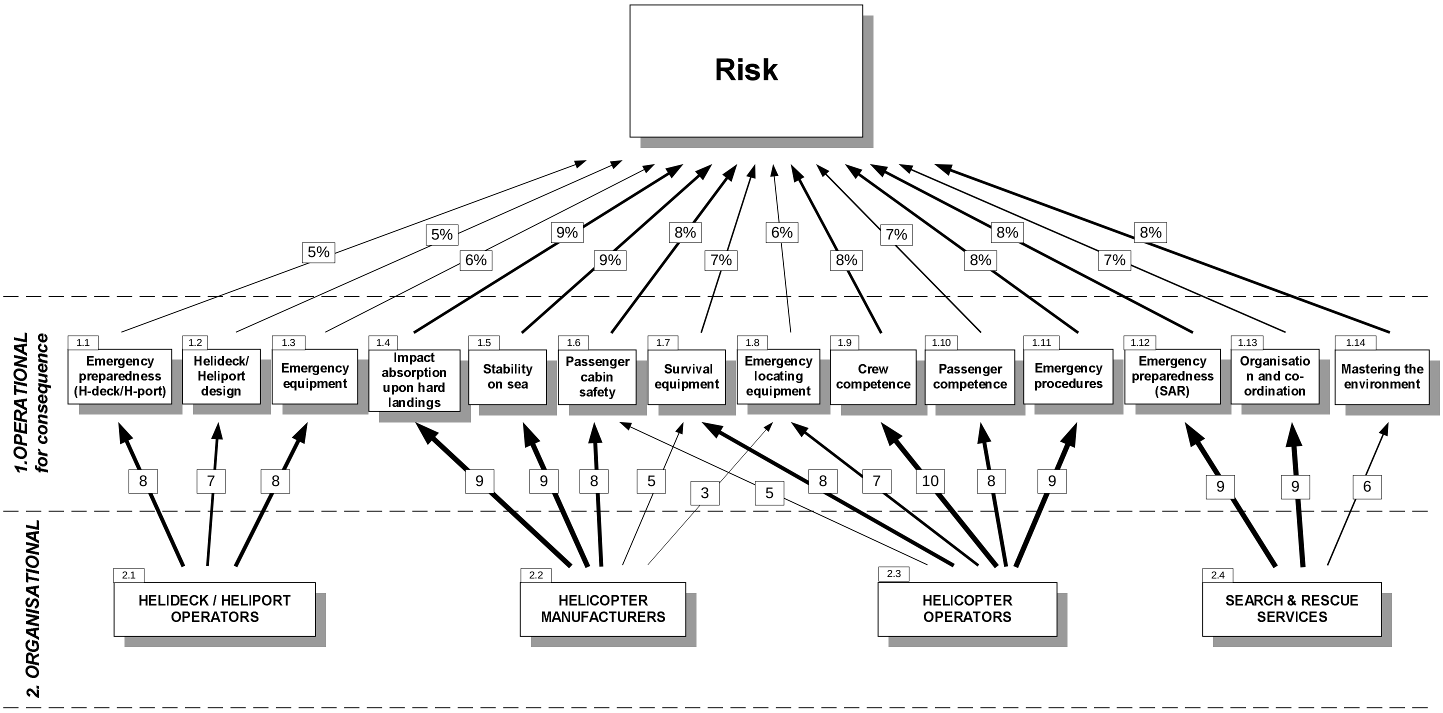

Figure 3.12 Effect of Organizational RIFs on the Operational RIFs for consequence (and on the total risk). (RIFs for frequency are fixed.)

Combining Figures 3.11 and 3.12, we see that there are three organizational RIF that are defined both with respect to frequency and consequence, one is defined for frequency only, and one is defined for consequence only. So in total we consider five organizational RIFs, and the overall results concerning these are summarized in **Figure 3.13**.

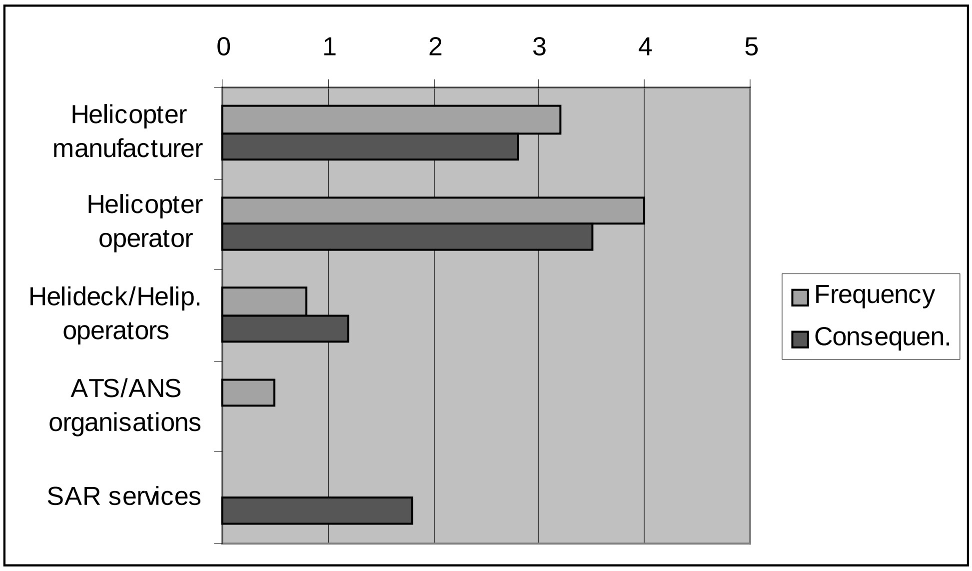

Figure 3.13 Importance of Organizational factors (derived from Figures 3.11 and 3.12): Ability of the Organizational RIFs to affect risk by influencing accident frequency and accident consequence, respectively; (relative numbers are relevant only).

Some qualitative results are presented below

- *Helicopter Operator* is the organizational RIF with the highest influence on risk. Actually when we split the influence, and consider the effect respectively on operational RIFs for frequency and consequence, we see that *Helicopter operator* has the highest effect for both categories. These effects relate primarily to the following issues:

  - Implementation of basic maintenance program and its further adaptation and revision
  - Responsibility to ensure that modifications repairs are in compliance/conformance with JAR-29
  - Crew seats and pilot equipment
  - Cockpit equipment and standardisation
  - Modifications
  - Flight Operations Manual
  - Crew Resource Management CRM
  - Periodic Flight Training PFT

- *The Helicopter Manufacturer* is the next operational RIF that has a high importance both with respect to frequency and consequence RIFs. These effects relate primarily to the following:

  - Developing new helicopter types, cockpit and equipment design and e.g. electronic equipment
  - Developing Basic Maintenance Program
  - Developing Airplane Flight Manual

- *The Helideck/heliport Operators* has some effect on both frequency and consequence RIFs

- *The SAR service* has a significant effect on the risk via its effect on RIFs for consequence (but none on the RIFs for frequency).

- *The ATS/ANS Operator* has some effect on the risk via its effect on RIFs for frequency (but none on the RIFs for consequence).

3.5 Effect of regulatory and customer related RIFs

At Level 3, the RIFs include Regulatory Authorities, Organizations and Customers. These aspects are elaborated in **Appendix E**. The following major issues are identified concerning these RIFs' influence on helicopter safety:

- *The Customers' willingness to invest in safety measures*
- *The helicopter transport contracts*
- *Requirements to the Helicopter Landing Officer (HLO) function*
- *Customers' co-operation*
- *Responsibility for the Helicopter Flight Information Service (HFIS)*
- *Responsibility for the conditions on the Helidecks*
- *Formulation of safety objectives*
- *Interface between different regulations (The Petroleum Act and The Aviatrion At)*
- *Integration of Risk Analyses/Risk Assessments for helicopter and petroleum activity*
- *Co-operation between the surveillance authorities.*

3.6 Changes in risk after 1990

Here the model is applied to assess the change of risk in the period 1990-1998 and in the period 1998-2008, respectively.

3.6.1 Changes in operational RIFs after 1990

Table 3.10 presents the estimated changes in status of the nine RIFs for frequency and the 14 RIFs for consequence during the two time periods 1990-1998 and 1998-2008. These changes are obtained by means of expert judgements. Positive change (+) means an improvement (higher safety), and negative change (-) means a deterioration (reduced safety). Thus, The given percentage represents the improvement in the status of the RIF in question. The corresponding changes in risk for the two time periods can now be assessed, using the model described in Sections 3.2 and 3.3 (cf Tables 3.7, 3.8 and 3.9). The results are presented in Sections 3.6.2 and 3.6.3 below.

For the frequency RIFs the estimated change in status can be directly related to the increase/reduction in accident frequency caused by the RIF in question. If this change equals - 100%, then the contribution to accident frequency (and risk) from this RIF will equals 0.

However, the risk reduction, which is the result of improving the status of a consequence RIF, is much more uncertain. The experts were unable to assess the actual effect with respect to reduced number of fatalities, resulting from a given improvement of a RIF for consequence. The quantification used here means it will have approximately the same *total* effect on risk when you either improve *all* 14 consequence RIFs with a fixed %, or when you improve *all* 9 frequency RIFs with the same %.

Table 3.10 Estimated changes in status of all RIFs during two time periods
("+" means improvement/higher safety)
("-" means deterioration/reduced safety)

RIF categories		Operational RIFs	Changes in RIF status 1990-98	Changes in RIF status 1998-08
Frequ-ency	Aircraft technical dependability	**1.1 Design and continuous airworthiness**	**+ 10%**	**+7%**
		1.2 Operators maintenance	**+ 10%**	**+7%**
		1.3 Modifications and repairs	+ 1%	
	Aircraft operations dependability	**1.4 Operations working conditions**	**+ 20%**	+ 5%
		1.5 Operations procedures	**+ 8%**	
		1.6 Human behaviour	+ 3%	- 3%
	Other conditions	**1.7 ATS/ANS**	**+ 30%**	**+ 40%**
		1.8 Helideck and heliports	**- 10%**	**- 10%**
		1.9 Environment	**- 10%**	**- 10%**
Conse-quence	Helideck/ heliport	1.1 Emergency preparedness (H-deck/H-port)	+ 7%	- 10%
		1.2 Helideck/heliport design	**- 7%**	**- 10%**
		1.3 Emergency equipment	+ 3%	+ 1%
	Crash-worthiness	1.4 Impact absorption upon hard landings	+ 5%	+ 10%
		1.5 Stability on sea	+ 5%	- 5%
		1.6 Passenger cabin safety	+ 5%	+ 5%
		1.7 Survival equipment	+ 5%	+ 5%
		1.8 Emergency locating equipment	**+ 10%**	**+ 30%**
	Crew & Pax emergency preparedness	1.9 Crew competence	+ 5%	
		1.10 Passenger competence	+ 5%	- 2%
		1.11 Emergency procedures	**+ 10%**	+ 5%
	Search and rescue operations	1.12 Emergency preparedness (SAR)	- 2%	- 2%
		1.13 Organization and co-ordination		
		1.14 Mastering the environment	+ 2%	

3.6.2 Changes in risk level 1990-1998

Using Table 3.10, the following estimate for the change in risk <u>from 1990 to 1998</u> is obtained:

- <u>*The estimated reduction in risk for 1990-1998 is 12%.*</u>

About 7% of this risk reduction is attributed to changes in the nine operational RIFs for *frequency*. The remaining 5% reduction is attributed to changes of the fourteen operational RIFs for *consequence.*

If we accept that the average risk over the period 1990-1998 is 1.85 fatalities per million person flight hrs (i.e. equal to the statistical risk given in Section 3.1), it follows from the result stated above that:

Estimated risk in 1990 = 1.97 fatalities per million person flight hrs
Estimated risk in 1998 = 1.73 fatalities per million person flight hrs
Estimated risk reduction = 1.97-1.73 = 0.24 fatalities per million person flight hrs

Thus:

- *Estimated reduction in risk from 1990 to 1998 equals 0.24 fatalities per million person flight hrs, (assuming the risk level of 1990-98 is 1.85 fatalities per million person flight hour)*

This change is investigated further to identify the major sources of the risk reduction:

1. The risk reduction due to improvement in RIFs for ***frequency*** is mainly due to the following factors:

   - *Aircraft technical dependability*. Improvements in RIF 1.1 Design and RIF 1.2 Operators maintenance are together estimated to give a risk reduction of about ***2.8%.*** A major contributors to this improvement are the introduction of HUMS, but there are also some design improvements (e.g. rotor system of Mark II, landing gear and airframe).

   - *Aircraft operations depenability*. Improvements in RIF 1.4 Operations working condition, RIF 1.5 Operations procedures anf RIF 1.6 Human behaviour are together estimated to give a risk reduction of about ***3.3%.*** Here the improvements in RIF 1.4 are estimated to have given the highest effect. This relates to improved working conditions; e.g. physical conditions in Mark II and Sikorsky S-76 and improved management/employee participation, improved QA in operations, and improved procedures (FOM, HFM and checklists).

   - *Other conditions*:

     ***** *ATS/ANS.* Improvements in RIF 1.7 ATS/ANS is alone estimated to give a risk reduction of about ***3.0%.*** Improvements relate to Class E air space Statfjord CTA, radar/radio coverage, approach conditions and procedures at heliports, and training of radio operators.

     * The changes in *RIF 1.8 Helideck and Heliport* and *RIF 1.9 Environment* together lead to a risk increase of ***2.1%*** (see below).

2. The risk reduction due to improvement in RIFs for ***consequence*** is mainly due to the following factors:

   - *Crashworthiness***.** Improvements in the five RIFs for crashworthiness (RIF 1.4 - RIF 1.8) are together estimated to give a risk reduction of about ***3 %*** (these contributions are in the same order of magnitude.) This relate e.g. to impact absorption and stability on sea, GPS.

   - *Emergency preparedness***.** Improvements in RIF 1.9 Crew competence, RIF 1.10 Passenger Competence and RIF 1.11 Emergency procedures are together estimated to give a risk reduction of about ***2%.*** An improvement in RIF 1.11 is alone estimated to give a risk reduction of about 1%. These improvements relate to improved crew/passenger competence (e.g. training).

- *Helideck/heliport*. Changes for Helideck/Heliport (RIF 1.1 - RIF 1.3) together accounts for a minor risk reduction (less than ***0.5%)*** There are both improvements and degradations that contribute to this figure. Improvements relate e.g. to more systematic training of HLO and standard clothing of helideck personnel.

- *Search and Rescue***.** Changes in SAR operations do not contribute to risk increase/decrease

In particular we point out the areas where risk has increased:

- *Helideck/heliport* have caused a significant risk increase. This relate to:

  - poor location of helidecks on FPSOs
  - increased no of unmanned helidecks
  - reduced helideck sizes.

  In addition, an increase in number of take off/landing per million flight hours (e.g. more shuttling) also causes an increase in risk (when risk is measured in fatalities per million person flight hours). This aspect is not properly accounted for in the model. However, assume there is an increase in Helideck/heliport accident exposure of say 20% (for the given number of flight hours). Since these I/A categories account for about 25 % of the risk, this factor alone implies an increase of overall risk of about 20% · 25% = 5%. At the same time we might slightly reduce the exposure to other accident categories. But the argument shows that Helideck/heliport accidents should be an I/A category of increased concern: The safety per take/off landing is reduced, and at the same time is (probably) the exposure per flight hour increased!

- *Environment* cause a significant risk increase. This relates to:

  - downgrading of the Aviation Meteorological Services (offshore weather observers with local experience replaced by automatic registration of meteorological data, e.g. sight, clouds
  - trends towards more heavy weather conditions, if bad weather occurs in the first place.

- *Human behaviour*. Negative trends relate to increased competition and tempo has raised the stress level. Hence, pilots more often experience fatigue.

- *SAR***.** There is an overall reduction in the number of radio stations/radio watchmen.

3.6.3 Changes in risk level 1998-2008

When we use the predicted changes in RIFs for the period 1998 - 2008 (Table 3.10) we get:

- ***The estimated reduction in risk from 1998 to 2008 equals 5%***
- ***The estimated reduction in risk from 1998 to 2008 equals 0.08 fatalities per million person flight hrs, (assuming the risk level of 1990-98 is 1.85 fatalities per million person flight hour)***

- ***About 50% of the estimated risk improvement for the next ten years is due to predicted improvements in the RIFs for frequency, and the remaining 50% is due to predicted improvements in the RIFs for consequence.***

The expected contributors to a positive trend are:

- *Crashworthiness* (RIF 0.2 for consequence): The S-92 helicopter will satisfy the more strict JAA crashworthiness requirements (JAR-29); some improvements on *Passenger cabin safety* (S-92); improved *Survival equipment*: EC 155 self erecting raft and survival suits of new design; improved *Emergency locating equipment*: M-ADS; improved radar coverage; 406 MHz ELT.
- *ATS/ANS* improvements: radar Ekofisk/Jotun; M-ADS, HFIS moved ashore and operated by certified controllers; Helgeland TMA, DGPSm; extended Class E air space
- *HUMS* will mature
- *Airframes* are expected to experience continued improvements (improved structural design and increased use of composit materials)
- *Environmental control system:* some improved systems are expected
- *Physical working conditions***:** will be improved in new helicopter types
- *Emergency procedures:* increased use of flight simulators; increased implementation and further development of the CRM concept (due to the JAR-OPS and JAR-FCL requirements); human factor courses (training) is expected to be further developed (due to the JAR-FCL requirements)
- *Passenger cabin safety:* some improvements are expected (in the S-92)
- *Heliports:* improved approach conditions; since 1994 subject to systematic approval and surveillance by the NCAA (Luftfarsinspeksjonen/Luftfartstilsynet); the introduction of more stringent practise of closing heliports for snow-clearing.

The three first mentioned above are the most important with regard to risk reduction.

- The listed improvements for Crashworthiness give a predicted risk reduction of about 4%; half of which is accounted for by *Emergency locating equipment*. (However, deterioration in *Stability of sea* gives a risk increase, so the overall reduction is only about 3.5%).
- Improvements in *ATS/ANS* offer a predicted risk reduction of about 3%.
- Finally, a further risk reduction due to the HUMS is predicted to about 2%

The expected contributors to a negative trend are:

- *Helideck*: Poor location of helidecks on FPSOs (and an increased number of FPSOs), reduced helideck size, reduced number of personnel designated for helideck duty only (and an increased number of unmanned helidecks), the implementation of JAR-PS Take-off and landing procedures.
- *Operations procedures*: An increased use of *offshore alternates* may occur. (Note that there are different views among the experts regarding the possible risk influence of this issue.)
- *Stability*: The S-92 is expected to be less stable on water than the present Super Puma.
- *Operations working conditions* are becoming worse by the implementation of JAR-OPS (e.g. increased work hours), and a diminution of Customer's own (stricter) requirements is judged possible.
- *Environment*: More heavy weather conditions due to an increased activity level further north, Aviation Meteorological Services further downgraded (no on shore weather observers during night).

- *SAR*: the number of Sea King SAR helicopters may be reduced; and a reduction in the number of radio stations / radio watchmen is foreseen.
- *Passenger competence*: a reduction in pax underwater training is expected.

The most significant contributor to increased risk is Helideck (close to 3%). Reference is made to the comment on helideck/heliport made in Section 3.6.2.

3.6.4 Conclusions regarding changes in risk after 1990.

It should be emphasised that the estimated risk improvements are rather small for both periods considered. This might be seen as a paradox, compared to the result of the statistical analysis, and provided that there has been a risk reduction of about 50% from the period 1966-90 to the period 1990-98. However, the above result is actually not in conflict with the statistical data. The statistical data relates to the *average* for the period 1966-90 and 1990-98, respectively. So, one reasonable explanation might be that the most significant changes have occurred during the period prior to (or close to) 1990. This is supported by the trend curves of the statistical data, which indicate a rather sudden drop in the risk about 1990 and no further significant drop after 1990 (see Section 3.1). This is quite consistent with the results of the analyses presented above.

According to the above results it is also predicted that the improvement during the period 1998-2008 will be less than that for the period 1990-1998. This conclusion seems rather independent of model uncertainty (and essentially stems from the input provided in Table 3.10):

- The risk reduction due to changes that affect the operational RIFs for *frequency* will in the next decade be about on third of the reduction experienced in the period 1990-98 (approx. 2.5% as compared to 7% in the previous period).

- The risk reduction due to changes that affect the operational RIFs for *consequence* will in the next decade be about on half of the reduction experienced in the period 1990-98 (approx. 2.5% as compared to 5% in the previous period).

4. DETAILED CONCLUSIONS

In this chapter, the detailed conclusions are summarised and related to the objectives of the study, which are as follows (cf. Section 1.3 Project objectives):

- Give an estimate of the present risk level by helicopter transport in the North Sea, and a comparison with the risk level presented in the first Helicopter Safety Study (HSS-1).
- Elaborate the reasons why the risk has improved (or decreased) during the period 1990-98. In other words, establish the effects of actual changes in relevant *Risk Influencing Factors* - RIF's (e.g. operation patterns, fuel reserves/alternates, HUMS, Radar etc.).
- Estimate the corresponding change in risk level over the period 1990-98.
- Identify the planned and most likely changes in the Risk Influencing Factors during the next decade (1998-2008), and identify the changes which will have the most significant impact on the Risk Level in this time period (presupposed the assumed changes do occur).
- Give an estimate of the corresponding effect on the Risk Level in the next decade.
- Give recommendations for further risk reduction.

Observe that, in this Report, "<u>risk</u>" is measured as the number of fatalities per million person flight hours, unless stated otherwise. "<u>Statistical risk</u>" is risk estimated entirely on the basis of statistical accident data. The terms "<u>estimated risk</u>" and "<u>predicted risk</u>" are used for estimates based on statistics in combination with Expert Judgements.

First, in Section 4.1, the average statistical risk level for 1990-98 is presented.

When studying the other sections it is recommended to relate the mentioning of the various Risk Influencing Factors (RIFs) to the Frequency Influence Diagram and the Consequence Influence Diagram, respectively. To facilitate this, turn up versions of the diagrams are located at the very end of this Main Report, as well as at the end of Volume II - Appendices.

*It should be noted that in this Chapter 4, the abbreviation **RIF F** refers to the <u>F</u>requency Influence Diagram, while **RIF C** refers to the <u>C</u>onsequence Influence Diagram. The diagrams are explained in Chapter 2 Approach.*

All results in Sections 4.2 – 4.6 are based on expert judgements as well as the accident data, using a risk model. The Sections 4.2 - 4.4 provide a discussion of the importance of the RIFs at Level 1, 2 and 3, respectively (cf. the Influence Diagrams). Sections 4.5 and 4.6 give the estimated changes for the time periods 1990-98 and 1998-2008. Finally, this chapter presents a discussion on further improvement measures and potential threats.

4.1 The risk estimated from statistical data ("statistical risk")

The statistical analyses (the accident data for 1990-1998) have given the following results:

- ***For the time period investigated in HSS-2 (i.e.1990-98) the estimated (statistical) risk for offshore helicopter transport in the North Sea equals <u>1.9 fatalities per million passenger flight hours</u>. In the Norwegian Sector there were 2.3 fatalities per million passenger flight hours, as opposed to 1.6 in the British Sector.***

- ***The statistics shows a risk reduction close to 50% from the first period (i.e. 1966-90, investigated in the HSS-1) to the last period (1990-98), see Figure 4.1. However, the accident figures are subject to great statistical variations. Hence, the true extent of the risk reduction is rather uncertain.***

- ***During the last period (1990-98) there have been altogether 15 accidents (Norwegian and British Sector combined). This equals approximately 1.0 accident per million person flight hours.***

- ***During the same period (1990-98) three fatal accidents have occurred, with a total of 29 fatalities. This corresponds to 9.7 fatalities per fatal accident and 1.9 fatalities per accident.***

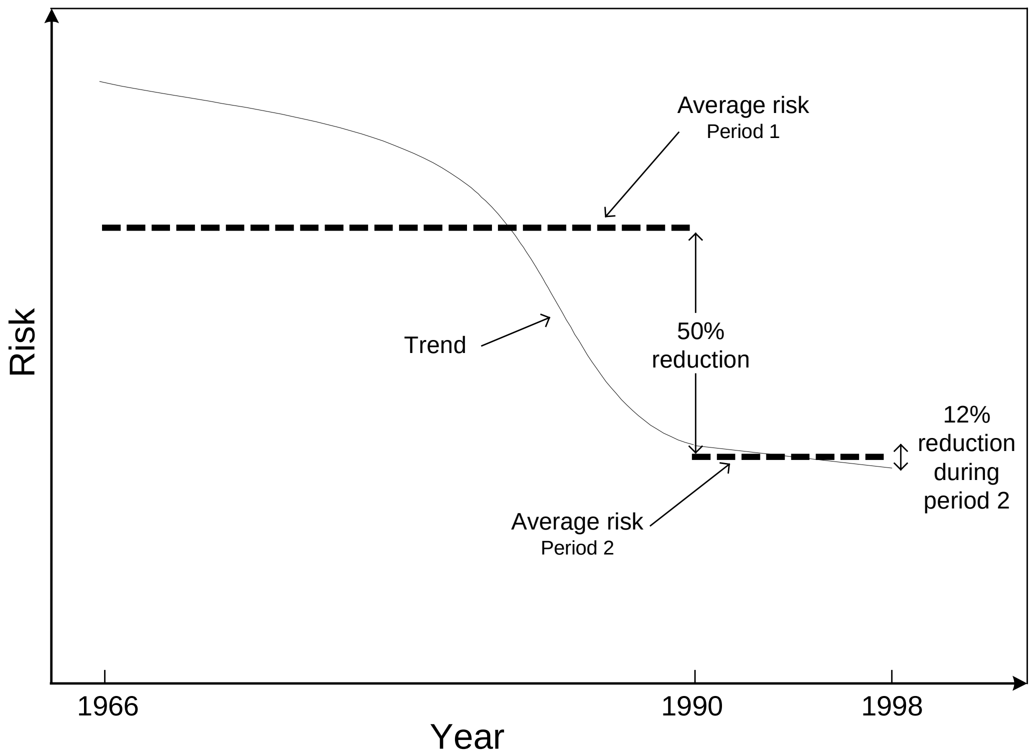

Figure 4.1 Illustration of estimated risk level for 1966-1998. Norwegian and British Sectors. The estimates of "Average risk" (Periods 1 and 2) are entirely based on the statistical data for these two periods. The given "Trend" for Period 1 (1966-1990) is included to give an indication of the assumed trend, whereas the given "Trend" for Period 2 (1990-1998) is derived from expert judgements.

4.2 Risk and Operational Risk Influencing Factors (RIFs)

Referring to the identified Incident / Accident categories, the following conclusions are drawn:

- ***The Incident/accident (I/A) category that contributes most to risk is "Collision with terrain, sea or building structure", followed by "Critical aircraft system failure during flight" and "Incident/Accident by takeoff or landing at Helideck"***

At Level 1 there are Operational RIFs for frequency and consequence respectively (cf. the influence diagrams, Figures 2.2 and 2.3). The importance of these RIFs with respect to the total risk is ranked as follows:

- ***"Human behaviour" of the helicopter crew (RIF F 1.6) is the operational RIF for frequency, which contributes most to the total risk.***

- ***"Design and continuos airworthiness"(RIF F 1.1) is the operational RIF for frequency, which is ranked second with respect to the contribution to the total risk.***

- ***Impact absorption upon hard landings"(RIF C 1.4), "Stability on sea" (RIF C 1.5) and "Passenger cabin safety"(RIF C 1.6) are the three Operational RIF for consequence which contributes most to the total risk. Observe that all these belong to the category (0.2) "Crashworthiness" (see Figure 2.3). "***

Accident frequency is investigated separately, without taking the accident consequence into consideration.

For the eight I/A categories the conclusions are as follows:

- ***"Critical aircraft system failure during flight" is the most frequent I/A category, as it accounts for 38% of the accidents.***

- ***"Incident / Accident by takeoff or landing at Helideck" is another frequent I/A category, accounting for 27% of the accidents.***

Concerning the operational RIFs for frequency the following result is found:

- ***"Design and continuos airworthiness" (RIF F 1.1) is the Operational RIF which gives the largest contribution to accident frequency, accounting for about 28% of the accidents.***

A similar investigation of the ***accident consequence*** concluded as follows:

- ***The I/A category with the highest accident consequence (number of fatalities, given that an accident has occurred) is "Near miss or mid-air collisions with other aircraft (MAC)".***

- ***The I/A "Collision with terrain, sea or building structure" is ranked number two with respect to consequence.***

- ***None of the operational RIFs for consequence have a particularly high contribution to total risk. However, the RIFs related to Crashworthiness (RIF C 1.4 - 1.8) are the most important contributors.***

Considering the input from the expert judgements the accident consequence averaged over all I/A-categories equals 2.7 fatalities per accident for the period 1990-98. This value differs from the statistical value (1.9). One reason for this is that the I/A category *"Near miss or mid-air collisions with other aircraft (MAC)"* has not happened during the period and hence is not represented in the statistics. However, if MAC occurs, the number of fatalities are expected to be high.

4.3 Organisational Risk Influencing Factors (RIFs)

At Level 2 in the Influence Diagrams there are in total five Organisational RIFs that affect the Level 1 RIFs for frequency and/or consequence (see Figures 2.2 and 2.3). Both these effects of Organisational RIFs on risk are investigated. The analysis gave the following result:

- ***The "Helicopter Operators" (HOs), have the highest influence on risk. The HOs are ranked number one both regarding frequency (RIF F 2.2) and consequence (RIF C 2.3)***

- ***The "Helicopter Manufacturers" are ranked number two, both regarding frequency (RIF F 2.1) and consequence (RIF C 2.2).***

- ***The three operational RIFs "Helideck/Heliport Operators" (RIF F 2.4), "Search & Rescue Services"(RIF C 2.4) and "Air Traffic / Air Navigation Service Organisations" (RIF F 2.3) are affecting the risk as well, but to a lesser extent.***

The management interviews have revealed some additional issues related to safety:

- *Frequent changes in the HO's company ownership*
  There have been several changes in company ownership the last ten years, due to increased internationalisation. The international group model implies a less uniform helicopter fleet, in addition to foreign standards. Both may affect safety in a negative way.

- *The introduction of the HUMS was the major improvement*
  Although still far from fully developed, the introduction of the HUMS is unanimously judged to be the most significant isolated safety improvement measure during the last decade.

- *Helicopter safety targets have improved*
  The HO's safety targets have changed during the last decade. For example, 10 years ago one of HO's safety target was maximum 0,8 incidents, serious incidents and accidents per 1.000 flight hours. Today, the corresponding target is 0,1.

- *The co-operation and exchange of safety-related information between the HOs have improved significantly*
  The present co-operation concerns, for example, common limitations in the operations procedures, when needed. The information exchange concerns experienced occurrences etc. On the other hand the HOs do not agree on the question, whether safety should be allowed to be a competitive factor.

4.4 Regulatory and Customer related Risk Influencing Factors (RIFs)

At Level 3, the RIFs include Regulatory Authorities, Organisations and Customers. The following major issues are identified concerning these RIFs influence on helicopter safety:

- *The Norwegian customers have very willingly invested in safety measures*
  The HOs praise the Norwegian oil companies' willingness to invest in expensive projects like the HUMS and the M-ADS, in order to improve flight safety.

- *Different views on the helicopter transport contracts*
  Regarding the helicopter transport contracts, there are some quite serious disagreements between the HOs and the Customers. The disagreements can be summarised as follows:

  - The HOs have experienced that since 1990 the customers have demonstrated a continuos and increasing attention to cost reduction efforts when entering new contracts[23]. The HOs, supported by the NCAA, express concern that continued focus on cost reduction can be at the expense of safety issues. The resulting effect could be a number of small, but accumulating cuts in the inherent safety margins. The HOs claim that this unfortunate trend has to be stopped, before accidents do occur. Already, an increasing number of maintenance errors can be observed, due to personnel reductions in the maintenance department.

  - The customers are of the opinion that the owners and top management of the HOs themselves are responsible for this development, if verifiable, not the customers. In the customers view the competition has resulted in more suitable prices, higher quality standards and improved flight safety, flexibility and service.

  In SINTEF's judgement, the arguments demonstrate a need for a set of safety-related Standard Contract clauses on offshore helicopter transport in the North Sea, combined with close attention to the implementation and follow-up of Safety Management and Flight Safety Programs (cf. JAR-OPS 1.3)

- *Requirements to the Helicopter Landing Officer (HLO) function*
  In general, the NCAA has no objection to using personnel without any formal background from aviation for this job, provided they have the required training. The OLF is at present preparing a standard for the HLO function.

- *Improved Customers' co-operation through OLF*
  In SINTEFs judgement it is not beneficial to safety that some customers have own, not standardised operations procedures, emergency equipment requirements etc. The OLF initiatives to produce common standards, for example with regard to the above mentioned HLO function, common North Sea operations procedures and helideck requirements are highly appreciated by the HOs and will contribute to risk reduction.

- *The Helicopter Flight Information Service (HFIS)*

  It has been suggested to move the HFIS ashore. Different opinions are disclosed regarding this issue:

  - The HOs have no objections to moving the HFIS ashore, provided the service is maintained. This would imply full radio coverage in the different offshore fields and education of offshore radio personnel and helideck personnel, to give correct information to pilots about the weather and other operational matters.

  - In the ATS' opinion, the HFIS should be established at the ACC responsible for the ATS in the area. If so, the quality of the services would improve, due to better surveillance equipment, a better overview of the traffic situation and more professional personnel. However, a consequence would be an increased need for Air Traffic Controllers.

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[23] In general, the price per flight hour has been reduced by 20-30% since 1990.

- The NCAA opinion is that the HFIS should continue to be stationed at the installations. However, the NCAA should work out a requirement specification for the HFIS, to ensure a satisfactory and standardised level of competence. According to the NCAA, the use of fully certified offshore Air Traffic Controllers would probably result in delays caused by obtaining flight clearances etc., but not necessarily improve flight safety.

- In the NPD's view questions could be raised regarding the sharing of responsibilities that would result, if the HFIS were moved ashore. Splitting the functions (e.g. flight information and co-ordination, particularly of shuttling traffic) would result in ”less competence in the same room”. Also, the informal co-operation between the HFIS and marine surveillance and the logistics co-ordination commonly practised in the present HFIS-units may be affected. On the other hand there may be possible advantages of splitting these services, for example by connecting several marine radar pictures on the screen.

▪ *Who should be responsible for the conditions on the Helidecks?*
The question is raised, whether it is reasonable to hold the HOs responsible for the conditions on the helideck, in particular if several HOs are using the same deck. The NCAA could undertake this responsibility. Today, the owner of the helideck is responsible for the deck, the helideck crew, the relevant equipment and the QA-system. The HOs are responsible for checking that the owner performs his duties as described in the manuals and in compliance with the BSL D. A separate NORSOK standard on helidecks is presently being prepared.

▪ *The NCAA and the ATS safety objectives should be bettered*
The NCAA and the Air Traffic Services (ATS) should have more definite safety objectives for offshore helicopter transport than is the case today. For example, the present NCAA general policy / safety objective is that “the safety in Norwegian aviation shall at least be at the same level as in other industrial nations.” The ATS policy is to offer the offshore services on the basis of “normal” (i.e. onshore) criteria, for example with regard to the density and complexity of the traffic.

▪ *The interface between different regulations create problems*
It constitutes a problem to ATS that both *The Petroleum Act* and *The Aviation Act* regulates the offshore aviation in Norway. This implies that the oil and gas companies are responsible for the safety, but dependant of the quality of the ATS activities. Because the ATS apply own criteria regarding meteorological conditions, traffic density etc., the question of acceptance limits (“what is safe enough?”) will arise. Hopefully, a responsibility elucidation now in progress will clarify the situation.

▪ *Risk assessments should include all helicopter transport*
According to the NPD, the helicopter transport should be considered an integral part of the petroleum activity in all phases of the projects when it comes to risk analyses / risk assessments.

▪ *The co-operation between the surveillance authorities should be improved*
The Co-operation and co-ordination with the NCAA, the NPD and the NMD should be improved with regard to helideck surveillance activities at fixed installations, FPSOs and MoDUs.

4.5 Estimated changes in risk for the period 1990-98

The result of the estimation of the changes in risk is as follows:

- ***The estimated reduction in risk during from 1990 to 1998 is 12%, see Figure 4.1. This corresponds to 0.24 fatalities per million person flight hours. About 7% of the reduction is attributed to changes in the (Level 1) Operational RIFs for frequency. The remaining 5% are attributed to changes of the (Level 1) Operational RIFs for consequence.***

The risk reduction is mainly due to the following factors (giving <u>net</u> risk reduction in parentheses, after subtracting possible risk increases). Here we do not distinguish between frequency and consequence factors. When found appropriate, the operational factors are also grouped to present the total effect of the corresponding Level 0 RIFs (cf. Figure 2.2 and 2.3):

- ***"<u>Aircraft technical dependability</u>" (2.8%)***
  A major contributor to this improvement was the introduction of the HUMS. The general opinion is that the introduction of HUMS probably was the most significant isolated safety improvement measure during the last decade. Furthermore, it has been suggested that the implementation of the ISO 9000-series has increased the consciousness and willingness to adhere to the documented maintenance requirements.

- ***"<u>Aircraft operations dependability</u>" (3.3%)***
  The improvement is mainly related to the working conditions in cockpit. Also, it has been suggested that the implementation of the ISO 9000-series has increased the consciousness and willingness to adhere to the SOPs. At last, but perhaps not least, the concepts of <u>Safety Management</u> in general and <u>Flight Safety Programs</u> in particular have been introduced during the last decade. There is reason to believe that the general attention to these issues have contributed to an increased safety consciousness in aviation and, hence, a risk reduction.

- ***"<u>ATS/ANS</u>" (RIF F 1.7) (3.0%)***
  Improvements relate e.g. to Class E air space at Statfjord CTA, radio/radar coverage and conditions/procedures at heliports.

- ***"<u>Crashworthiness</u>" (3%)***
  This relates e.g. to impact absorption and the stability on sea.

- ***"<u>Crew & Pax Emergency preparedness</u>" (2%)***.
  This relates to improved crew/passenger competence (training).

- ***"<u>Helidecks and Heliports</u>" (RIF F 1.8)*** **(<0.5%)**
  Note that various RIFs (both for frequency and consequence) are contributing to this effect. A number of both improvements and deterioration have occurred.

<u>So, in total there has been a positive trend with respect to risk. However, particular attention should be paid to the changes that have contributed to risk *increase*:</u>

- ***"<u>Helidecks and heliports</u>" (RIF F 1.8 and RIFs C 1.1 – 1.3)***
  As stated above there have been both improvements and deterioration regarding the Helideck and Heliport conditions. The risk increase relates to poor location of helidecks, particularly on FPSOs and MoDUs, an increased number of unmanned installations / helidecks, reduced

helideck sizes and an increased number of takeoffs and landings per million flight hours (e.g. more shuttling). A separate study would be required to investigate this effect in detail.

- ***"Environment"* (RIF F 1.9)**
  Risk increase relates to the Aviation Meteorological Services being downgraded and trends towards more heavy weather conditions, combined with a possible increase in helicopter traffic further north.

- ***"Human behaviour"* (RIF F 1.6).**
  Increased competition between the Helicopter Operators has raised the general stress level; and pilots more often experience fatigue due to an increased tempo.

- ***"Search & Rescue Operations"* (RIFs C 1.12 - 1.14)**
  There has been an overall reduction in the number of radio stations/radio watchmen. It is assumed that this has made rescue operations more complicated.

4.6 Predicted changes in risk level 1998-2008

Like the previous decade, both positive and negative changes are expected for the next decade. However, the net result is assumed to be a further risk reduction:

- ***Based on the Expert Judgements the predicted reduction in risk from 1998 to 2008 is 5%, which equals 0.08 fatalities per million person flight hours. Thus, the improvement during the next decade is predicted to be less than during the past decade (1990-1998).***

The expected main contributors to a positive trend during 1998-2008 are (net risk reduction in parentheses):

- ***"Crashworthiness"* (4%)**
  The improvements relate to the following:
  - the new S-92 helicopter, which will satisfy the more strict JAA crashworthiness requirements (JAR-29),
  - some improvements on "*Passenger cabin safety"* (RIF C 1.6) related to the S-92,
  - improved "*Survival equipment"* (RIF C 1.7), in particular the EC 155 self erecting raft and survival suits of new design, and
  - improved "*Emergency locating equipment"* (RIF C 1.8), in particular the ADS-C (the present system) / ADS-B, improved radar coverage and the 406 MHz ELT.

- ***"The Air Traffic / Air Navigation Services"(ATS/ANS:* RIF F 1.7*) (3%)***
  Improvements relate to radar Ekofisk/Jotun; ADS, HFIS moved ashore (if operated by certified controllers); Helgeland TMA, DGPS and extended Class E airspace.

- ***The HUMS* (included in RIF F 1.2) (2%)**
  These monitoring systems are expected to mature during the next decade, and probably will contribute to a further risk improvement.

- ***The OLF guidelines for common North Sea procedures* (included in RIF F 1.5)**
  These guidelines are presently under preparation. They are expected to have a risk reduction effect.

The expected contributors to a negative trend during 1998-2008 are related to the following RIFs:

- ***"Helidecks" (included in RIF F 1.8 and RIFs C 1.1 – 1.3; close to 3% risk increase).***
  The reason for the risk increase is poor location of helidecks on FPSOs and MoDUs, combined with an expected increase in the number of such, and a reduced helideck size. In addition, a reduction in the number of personnel designated for helideck duty only is expected, as well as an increase in the number of unmanned installations. Finally, the implementation of the JAR-OPS: *Takeoff and Landing Procedures* is expected to increase the risk. This is because the JAA in these procedures, in stead of prescribing “Class 1” (zero probability) have accepted an inherent risk of a fatal accident in case of loss of power in one engine during takeoff or landing offshore. This is as opposed to the present Norwegian procedures.

  However, some of the predicted changes related to helidecks will contribute to a risk reduction, as well. For instance, the training of HLOs are expected to be improved in this period of time.

- ***"Stability on Sea" (RIF C 1.5)***
  The S-92 is expected to be less stable on water than the present Super Puma.

- ***“Operations Working Conditions” (RIF F 1.4)***
  The crew’s working conditions are becoming worse by the implementation of JAR-OPS (e.g. increased work hours). A possible reduction of Customer’s own (stricter) requirements is also foreseen.

- ***"Environment"(RIF F 1.9)***
  More heavy weather conditions are expected due to an increased activity level further north and a further downgrading of the Aviation Meteorological Services (no weather observers on shore during night).

- ***“Search & Rescue Operations”***
  The number of the Sea King SAR helicopters may be reduced, and there may be a reduction in the number of radio stations / radio watchmen.

- ***“Passenger Competence”(RIF C 1.10)***
  A further reduction of pax underwater training is expected.

- ***”Offshore alternate”(included in RIF F 1.5)***
  The use of the offshore alternate concept (Pre-Determined Point – PDP, “one-way fuel”) is expected to increase. However, there are different views on the possible safety effect of this issue.

4.7 Suggested improvement measures

Based on the information achieved in this project and the corresponding analyses, the following improvement measures are suggested. The measures are mainly organised according to the Frequency Influence Diagrams (see **Figures 2.2 and 2.3** or **Appendix F**), in the following order:

- Organisational factors (Level 2)
- Regulatory and customer related factors (Level 3)

The Helicopter Manufacturers

- The major technological improvement potential is related to the helicopters as such. The general view is that future changes in the helicopter design should primarily be initiated for safety reasons and not, for example, to further increase the aircraft payload and range.

- The following systems should be further developed and made more redundant:
  - the HUMS
  - the rotor systems
  - the flight controls systems
  - the one engine inoperative performance.

- Particular attention should be paid to a reduction of the "burn-in" problems related to new helicopter designs.

- The general communication and co-operation between the Helicopter Manufacturers and the Helicopter Operators and the Customers (oil companies) on safety matters should be improved.

- Simulators should be made available to the HOs, before new helicopter designs are launched at the market.

- The MSG-3 analyses should be made available to the HOs as a basis for tailoring their Maintenance Program and increasing the possibility of making high quality Risk Analyses.

- Increased competition between helicopter manufacturers would probably encourage further technological improvements and be beneficial to safety. However, it is not clear how this could be achieved.

The Helicopter Operators

- The cockpit design should be further standardised, in order to reduce the number of occurrences. The responsibility for this mainly rests with the HOs themselves, by ordering customised cockpit design. (However, rented helicopters would still be a problem.)

- The pilot behaviour should be made even more uniform. Enforcing firm operations procedures (ordinary and emergency) combined with exercise (drill) would increase the predictability of each crewmember.

- There should be an experience transfer from experienced captains to younger pilots.

- Close attention should be given to crew's working condition (e.g. working hours)

- The Crew Resource Management (CRM) concept should be extended to the technical / maintenance personnel, as well.

- The basic education and recurrent training of operative and technical personnel should be intensified.

- Continued use of offshore alternates should be re-assessed if other planned or proposed risk increasing changes are implemented (e.g. the moving of the HFIS ashore and the automation of weather observations). The reason for this is to prevent possible unfortunate and unforeseen combined effects.

- Firm attention to Safety Management in general and Flight Safety Programs in particular should be maintained (cf. JAR-OPS 1.3).

The The Air Traffic / Air Navigation Service Organisations

- The ADS technology should be further developed and upgraded to an ICAO certified tool for Air Traffic Control.

- Controlled airspace from 1.500 to 8.000 feet should be established in areas with heavy traffic. In combination with the ADS this would imply controlled air space below 1.500 feet, as well. Bilateral or multilateral agreements with foreign countries should be reached, in order to achieve full effect. Also, a frequent updating of positions by means of satellites would be necessary. (Full Radar coverage in the Norwegian *Sector* is not considered feasible.)

- Steps should be taken to improve the separation of military traffic from civil offshore helicopter traffic. To this end, the CAA-N / ATS should establish a co-operation with the Norwegian Air Force in order to have the ADS signals incorporated in the military air traffic control systems.

- The weather forecasts should be improved for offshore operations. According to the Expert Judgements there is a great improvement potential in this respect. In particular, this service should be based on a greater number of sources.

The National Authorities (NA)

- The NCAA should develop a general Risk Model, and engage itself more with Risk Analyses and Trend Analyses. The present lack of a general risk model, including a set of Risk Indicators, implies that the NCAA has to base its decisions on experience. In addition, an increased attention to Trend Analyses would contribute to early warnings of technical, human and/or operational failures.

- The NCAA should work out a requirement specification for the HFIS in order to ensure a satisfactory and standardised level of competence.

- The HFIS should be subject to surveillance by the NCAA.

- The regulations of unmanned installations should be further developed and detailed. The number of unmanned installations is expected to increase, making this issue even more important.

- The sharing of responsibility between the NCAA, the NPD and the NMD should be fully clarified and a superior, fully qualified agency should have the authority to make the safety-related decisions. In today’s system, many commendable initiatives are not accomplished due to unclear responsibilities, and hence a lack of funding.

- The NCAA should be the approval authority for all offshore helidecks subject to Norwegian jurisdiction.

- The established surveillance co-operation between the NCAA, the NPD and the NMD should be further developed.

- The revised NPD Regulations should be co-ordinated with the BSL in the best possible way.

- All Norwegian authorities should be required to exceed the minimum requirements in their invitation to tenders. It is felt that the authorities should be proactive and a good example to others. The contracts should be specified on the basis of operational experience and good knowledge of local conditions.

- In their surveillance activities, the national authorities should maintain firm attention to Safety Management in general and Flight Safety Programs in particular (cf. JAR-OPS 1.3).

The Customers (inclusive the Helideck Operators)

- Standard Contract clauses should be developed in co-operation with the HOs and the Trade Unions and implemented for all regular offshore helicopter transport (preferably at both sides of the North Sea). Such compromised Contract clauses should pay much attention to precise safety requirements and emphasise the customer's safety obligations, as well. Further, the contracts should reflect a sound and clear policy on the relationship between safety and price, and foster a consistent safety attitude (safety culture) by all parties involved.

- The Total Risk Assessment / Risk Analyses of manned and unmanned installations should consider the risk contribution from helicopter transport as a whole (i.e. in all project phases, between land and offshore, and shuttling).

- In their quality/safety audit activities, the Customers should maintain firm attention to Safety Management in general and Flight Safety Programs in particular (cf. JAR-OPS 1.3).

4.8 Needs for further clarification

The below mentioned are some issues that need further clarification, before the suggested risk reduction measures are implemented.

- *The Helicopter Flight Information Service (HFIS)*
  As mentioned, it has been suggested to move the HFIS ashore. It would be recommendable to further discuss the different opinions on this issue.

- *Controlled Air Space, Radar coverage and future use of the ADS*
  The possible introduction of controlled air space is presently subject to a separate Risk Analysis, assigned by the NCAA to SINTEF. Hopefully, this analysis will contribute to the solution of this issue.

- *The Basic Maintenance Programs*

It is recommended to clarify the reasons why the Basic Maintenance Programs issued by the Manufactures still are subject to heavy criticism from the HOs. Afterwards, the necessary corrective actions should be taken.

- *Helidecks and heliports*
  A separate study is recommended to investigate the effects of a possible increase in the number of unmanned installations/helidecks and takeoffs and landings per million flight hours. (The other issues related to helidecks will be straightened out in the current Helideck Study.)

4.9 Potential threats

The following potential future threats to safety are foreseen:

- There could be a gradual and unnoticed reduction in safety, finally resulting in a situation where all HOs are operating at, or close to, the minimum requirements. No one could guarantee that inspections and audits would discover such a trend. Today, for example in a difficult economic situation, it would be quite possible for the HOs to interpret the regulations in a way that would benefit the economy at the cost of safety. If, in addition to this, contracts should be awarded only on the basis of the lowest price and at the same time without quite unambiguous contractual obligations, safety will almost certainly suffer. To prevent this, complete and unambiguous contractual obligations are essential.

- If the forthcoming change in the age structure of the pilots is allowed to develop freely, safety could be jeopardized.

- If the anticipated shortage of fully qualified maintenance technicians occur, the continuous airworthiness of the helicopters could be jeopardized.

- If the professional communication between the HOs were reduced for competitive reasons it would imply a significant setback in safety.

- Contracts, which reward high regularity or even, impose penalties for low regularity *could* constitute a potential safety problem. In a situation with only one HO in the market, the problem would be evident.

5. REFERENCES

AAIB Bulletin no. 10/97, Ref. EW/C97/3/2.

Bråthen, P. Universitetet i Oslo, Institutt for informatikk: *Helikopterflyging på norsk kontinentalsokkel. Noen sikkerhetsmessige problemer, forslag til løsning og simulering.* Hovedfagsoppgave 1996.

Embrey, D. E.: *Incorporating management and organizational factors into probabilistic safety assessment*, Reliability Engineering and System Safety 38, p. 199 – 208, 1992.

Flight Safety Digest. Special FSF ALAR Task Force Report: *A Study of Fatal Approach-and-landing Accidents Worldwide, 1980-1996*. Vol 17 No. 2/3 February-March 1998 pp1-12.

Hansen, G. K., Hokstad, P., and Sneltvedt, J.: *A risk influence model for helicopter traffic*. Paper presented at ESREL, Munich 1999.

Helikopter Service A/S*: Luftoperativt konsept. Helikopter Operasjoner. Midtnorsk sokkel.* Mai 1998.

Hokstad, P., Øien, K. and Reinertsen, R.: *Recommendations on the use of expert judgement in safety and reliability engineering studies. Two offshore case studies*. Reliability Engineering and System Safety 61, pp 65-76. 1998.

Holden, K., Mathisen, L., Werenskiold, R., Ingstad, O., Paulsen, and Sten, T.: Safety *Study of High Speed Marine Traffic.* SINTEF Report STF38 A96415, 1997.

Ingstad, O., Rosness, R., Sten, T., Ulleberg, T., Rausand, M., and Lydersen, S.: *Helicopter Safety Study. Main Report*. SINTEF Report STF75 A90008, 1990.

Ingstad, O., Fallrø, P.J., Paulsen, T., Rosness, R., and Sundet, I.: *Metode for vurdering av fremtidig storulykkespotensial*. SINTEF Report STF75 A91027, 1991.

Luftfartsverket: *Konsept for helikoptervirksomhet på norsk kontinentalsokkel.* 1992-93.

Luftfartsverket: *Kriterier og prosedyrer for operativt bruk*. 1999.

Office of System Safety Federal Aviation Administration: A Report of Issues related to Public Interest in Aviation Safety Data. Washington, January 20, 1997.

Oliver, R.M., Smith, J.Q.: *Influence Diagrams, Belief Nets and Decision Analysis.* John Wiley & Sons Ltd. 1990.

Oljeindustriens landsforening: *Helikoptersikkerhet og arbeidsmiljø – anbefalte tiltak og retningslinjer.* 1999-04-21.

Paté-Cornell, M. Elisabeth, and Murphy, Dan .M.: *Human and management factors in probabilistic risk analysis: the SAM approach and observations from recent applications.* Reliability Engineering and System Safety 53, p. 115 – 126, 1996.

Paulsen, T.: *Risk Assessment Data. Accidents Involving Aircrafts and Helicopters*. SINTEF Report STF75 F95018, 1995.

Preventor: *Risk Levels on the Norwegian Continental Shelf. Final Report.* 25 August 1998.

Rogalandsforskning: *Helikoptersikkerhet og arbeidsmiljø. Undersøkelse av angst og ubehag i forbindelse med helikoptertransport*. RF-1998/279.

Rosness, R.: *Search for Safety*. *The Methodology and Process of Risk Influence Analysis.* Doctoral thesis. Norwegian University of Science and Technology (NTNU), 1999-38. Trondheim 1999.

Statoil: *Sluttrapport – Helikopterprosjektet.* 1998-07-01.

Werenskiold, P., Dyrhaug, A., Hokstad, P., and Sten, T.: *HSC Safety Assessment. Main Report: Risk Analysis and Safety Measures*. MARINTEK MT60 F98-082, 1998.

Øien, K. and Hokstad, P.: *Handbook for performing Expert Judgement*. SINTEF Report STF38 A98419.