TØI report 1354/2014

Ross Owen Phillips

Institute of Transport Economics
Norwegian Centre for Transport Research

An assessment of studies of human fatigue in land and sea transport

Fatigue in Transport Report II

TØI Report
1354/2014

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Ross Owen Phillips

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ISSN 0808-1190

ISBN 978-82-480-1565-9 Electronic version

Oslo, December 2014

Title:	An assessment of studies of human fatigue in land and sea transport	**Tittel:**	En vurdering av studier om trøtthet i land- og sjøtransport
Author:	Ross Owen Phillips	**Forfatter:**	Ross Owen Phillips
Date:	12.2014	**Dato:**	12.2014
TØI report:	1354/2014	**TØI rapport:**	1354/2014
Pages	98	**Sider**	98
ISBN Electronic:	978-82-480-1565-9	**ISBN Elektronisk:**	978-82-480-1565-9
ISSN	0808-1190	**ISSN**	0808-1190
Financed by:	The Research Council of Norway	**Finansieringskilde:**	Norges forskningsråd
Project:	3719 - Kunnskap om trøtthet og nedsatt vaktsomhet blant transportoperatører	**Prosjekt:**	3719 - Kunnskap om trøtthet og nedsatt vaktsomhet blant transportoperatører
Project manager:		**Prosjektleder:**	
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Key words:	Driver Fatigue Rail Road Safety Sea Tiredness	**Emneord:**	Jernbane Sjø Trafikksikkerhet Trøtthet Vei Yrkessjåfør

Summary:

Despite technological developments, human operator fatigue continues to threaten safe transport by road, sea, rail and air. The current report hopes to help improve research progress and application by reviewing research on fatigue in operators working in road, sea and rail, and assessing its quality (i) in relation to a broad operationalization of fatigue; and (ii) by structuring the findings using a fatigue-risk trajectory. The review finds that while the focus of studies is influenced by the transport sector of interest, there is good coverage of the effects of working time on sleep, sleepiness and experienced fatigue. However, progress towards an understanding of fatigue in transport is restricted by a range of different but narrow conceptualisations of the construct. Important contributors and outcomes to fatigue have also been overlooked. Our recommendations include that future studies employ a standard test battery for broader fatigue, and that they account for recovery from work during non-work life and the longer-term safety impacts of operator burnout. Better management of the risks of fatigue in transport requires that future studies address important knowledge gaps by attending to the broader concept of fatigue.

Sammendrag:

Til tross for teknologisk fremgang, er trøtthet blant operatører fortsatt en vesentlig trussel mot sikker transport. Denne rapporten har som mål å bidra til mer og bedre forskning samt økt anvendelse av forskningsbasert kunnskap om trøtthet i transport. Rapporten går gjennom og vurderer en rekke internasjonale studier på trøtthet i vei-, jernbane- og sjøtransport. Studiene vurderes ut fra en bred operasjonalisering av begrepet «fatigue», noe som er nødvendig for fullt ut å forstå og håndtere problemstillingene rundt trøtthet. Mange av studiene ser på effektene av arbeidstid på søvn, søvnighet og opplevd trøtthet. Imidlertid er forståelsen av trøtthet i transport begrenset av at man ofte bruker ulike og for smale definisjoner av «fatigue». Viktige faktorer som kan bidra til trøtthet, er ofte oversett, og det samme gjelder viktige konsekvenser av trøtthet. Rapporten anbefaler å anvende et standard målebatteri som kan brukes for å måle ulike aspekter av trøtthet. Det anbefales også at framtidig forskning i større grad tar hensyn til belastninger og muligheter for hvile som arbeidstakere har i livet utenfor arbeid. Framtidige studier bør også vurdere langsiktige sikkerhetsmessige effekter av trøtthet og utbrenthet. Bedre risikostyring i transport forutsetter at framtidige studier anvender en slik bredere forståelse av trøtthet for å bøte på svakhetene i de foreliggende studiene.

Language of report: English

This report is available only in electronic version.

Rapporten utgis kun i elektronisk utgave.

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Preface

This is the second report from the project «Fatigue in Transport» (FiT), which has been carried out within the TRANSIKK programme («Transportsikkerhet») of the Research Council of Norway. The main objective of the FiT project is to increase what we know about fatigue in human transport operators in the road, maritime and rail sectors in Norway. The first report from the FiT project was issued as TØI Report 1351/2014, with the title "What is fatigue and how does it affect the safety performance of human transport operators?". This was an account of how fatigue can be operationalised in order to study its prevalence and effects in human operators of land and sea transport. The present report uses the findings from the first report as the basis for assessment of applied international studies of human fatigue in road, rail and sea transport. By summarising the methodology and findings of studies conducted out across transport sectors, it also identifies conclusions about common findings, knowledge gaps, and ways forward for research and practice in the field of transport operator fatigue. The remainder of the FiT project will attempt to apply some of these conclusions to the study of fatigue in Norwegian transport operators.

The project manager and report author, Ross Owen Phillips, wishes to thank Torkel Bjørnskau, Fridulv Sagberg, and Tor-Olav Nævestad for comments and discussions in the development of the report, and Trude Rømming who has been involved in editing the report and preparing it for publication. Torkel Bjørnskau has quality assured the report. TØI also wishes to thank FiT Reference Group – Margareta Lützhöft, Ebba Wergeland, Emma Wadsworth and Anne Kari Rasmussen – for their contribution at the outset of this report.

Oslo, December 2014
Institute of Transport Economics (TØI)

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Summary:

An assessment of studies of human fatigue in land and sea transport

TØI Report 1354/2014
Author: Ross Owen Phillips
Oslo 2014, 98 pages English language

Field and survey studies measuring operator fatigue in land and sea transport are assessed against an argument that a broad operationalization of fatigue is required in order to fully understand it. Our assessment finds that the progress towards an understanding of fatigue in transport is restricted by a range of different but narrow conceptualisations of the construct. One result is that we know little about the relative prevalence of fatigue in different transport operators, a situation which could be improved using a standardised measurement battery for the assessment of operator fatigue. Further implications are that important contributors to fatigue, such as recovery from work during non-work life, have been neglected, as have some important outcomes such as the longer term safety impacts of operator burnout. Better management of the risks of fatigue in transport requires that future studies address important knowledge gaps by attending to the broader concept of fatigue.

Despite technological developments, human operator fatigue continues to threaten safe transport by road, sea, rail or air. One way to improve matters is to encourage understanding and application of research into transport operator fatigue. The current report hopes to help do this by reviewing and assessing research on fatigue in operators working in different transport contexts.

Assessment in terms of how fatigue is thought about

Fatigue is an abstract, diffuse and complex construct, with intractable psychological, physiological and performance aspects. The effect of fatigue on performance may be of ultimate interest to transport managers and regulators, but a conceptualization of fatigue solely in terms of performance will be problematic, not least because fatigue often does not clearly manifest itself in performance. Because of the risks involved, most transport operators are highly motivated to maintain performance in the face of experienced fatigue, and evidence suggests that they do this successfully, at least across the hours of a normal shift. Researchers increasingly accept that there are costs involved in maintaining performance, e.g. the operating strategy may be simplified or there may be longer-term health decrements because of the increased effort involved. These hidden or "latent" decrements may be detrimental to safety in ways that are not immediately obvious to either the operators or their organizations. In order to fully understand the effects of fatigue, there is a need to measure and account for fatigue in terms of how it is experienced, how it affects operator physiology, and how it can affect performance in both obvious and subtle ways. Reflecting this, the following definition of fatigue is employed as a basis for assessing how fatigue studies to date have operationalized the construct:

Fatigue is a suboptimal psychophysiological condition caused by exertion. The degree and dimensional character of the condition depends on the form, dynamics and context of exertion. The *context of exertion is described by the value and meaning of performance to the individual; rest and sleep history; circadian effects; psychosocial factors spanning work and home life; individual traits; diet; health, fitness and other individual states; and environmental conditions. The fatigue condition results in changes in strategies or resource use such that original levels of mental processing or physical activity are maintained or reduced.*

This definition implies that psychological and physiological aspects need to be measured in order to fully understand the state of fatigue. In order to understand the fatigue process, we need to characterize the form, dynamics and context of exertion, in addition to actual and latent performance. Studies can thus be assessed according to their relative treatment of the fatigue state and process. The above definition also accounts for sleepiness as an integral component of the experience and process of fatigue, in terms of the role of "rest and sleep history" and "circadian effects" in exertion. An interesting question is whether and how different studies account for sleepiness in their treatment of fatigue.

Assessment of knowledge using the fatigue risk trajectory

The implicit aim of many studies of human operator fatigue is to inform practice. One way to assess the extent to which they do this is to structure the knowledge collected from these studies according to different levels of fatigue risk management, using a version of Dawson & Fletcher's (2001) fatigue-risk trajectory modified to account for our broad conceptualization of fatigue. The modified trajectory is aimed at managers and regulators, and presents five levels at which they should monitor and provide countermeasures for fatigue in human transport operators:

1. Work time, work quality, non-work life quality.
2. Actual recovery from work.
3. Reports of fatigue and behavioural symptoms.
4. Fatigue-related errors.
5. Fatigue-related incidents and accidents.

86 studies on operators working in road, rail and maritime sectors

Our assessment was carried out on field or survey studies from the last 40 years that attempted to measure fatigue in human transport operators working in the road, rail or sea sectors. We retrieved 86 studies: 24 from shipping, 39 from the road sector and 23 from the rail sector.

Most of the road studies focus on poor sleep, working time and occupational and framework conditions as contributors to fatigue. Most involve long-haul truck drivers, though there are several studies of bus driver fatigue. In the road studies fatigue is often operationalized as generalized sleepiness, although several consider acute sleepiness or acute broader fatigue.

Rail studies are more concerned than road studies with assessing acute sleepiness due to recent schedules worked. There is also a greater focus on the longer-term effects of fatigue, and health-related factors arising because of shiftwork appears to be a particular concern. Despite this, chronic fatigue or burnout are rarely considered explicitly.

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Many studies on the causes of seafarer fatigue have tended to focus on the link between different watch patterns and sleep, especially for watch officers. Studies may survey a large number of crew, or there may be more intensive measurement of a few crew on a single vessel. Generalized fatigue has been operationalized using a range of standard measures. Self-reports on momentary fatigue or sleepiness are also common. Attempts to generalize about prevalence rates are complicated by the heterogeneous nature of shipping and the wide range of fatigue measures employed, although one study finds that seafarers generally report fewer fatigue symptoms than do truck drivers.

Need for a standardized measurement battery

As a result of our assessment we found that an understanding of fatigued states in transport operators is limited by studies using unique customized measures or one or two of a range of different standardized measures. Few studies assess the different dimensions of experiential fatigue. Understanding would therefore be improved if applied studies were to use a standard measure battery that captures not only acute and generalised broader fatigue and sleepiness, but the various important dimensions of experiential fatigue. Such a battery should include instructions on when fatigue and sleepiness should be measured in operators in relation to their work periods.

We identify four candidate measures for such a battery: the Epworth Sleepiness Scale, the Karolinska Sleepiness Scale, the Swedish Occupational Fatigue Index, and the Samn-Perelli measure of fatigue. Tables of average scores and shares of samples scoring above threshold scores on each constituent battery measure would improve understanding and help managers and regulators assess the severity of fatigue in different operator populations. Difficulties associated with the measurement of physiological aspects of fatigue might also be improved by standardization, together with a focus on naturalistic observations of operators in real world settings. Regarding operationalization of the fatigue state, we also find that there is a need for authors to be more explicit about their treatment of sleepiness in relation to fatigue.

A need to address both quantity and quality in work and non-work life

There is increasing recognition that the quality of work may be just as important as the quantity of work (i.e. work time) in terms of the effects on sleep and resulting fatigue. Given this, we find that there is a need to study how the psychosocial and physical quality of work interacts with working time to cause fatigue. We also find that the quality of life outside work has been overlooked as an important contributor to fatigue at work. While several studies in different sectors address the influence of framework conditions on fatigue, comparative studies of the different conditions faced by operators in different subsectors would illustrate more clearly to regulators and organizations, the effects of various business drives on operator fatigue.

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Better ways to study performance effects

Improved reporting of near misses and accidents in all sectors would help in the study of the role of fatigue. Self-reports of performance levels could be improved by standardizing the periods for which operators are asked to report on incidents of severe sleep (or falling asleep) while operating. Increased observation of fatigue preceding incidents in naturalistic settings would assist understanding, and increased use of operational parameters, such as brake and accelerator use patterns, may be preferable to invasive psychomotor performance tests. The way in which fatigue influences more complex aspects of performance (e.g. increased reliance on default mental schemas) has yet to be considered, but requires that such performance effects can be operationalized for study.

What else do we need to know to improve how we manage fatigue risks?

A consideration of the findings of the studies retrieved for this report in relation to our modified fatigue-risk trajectory confirms that while work time has been well studied, there is a need to consider how work time, work quality and non-work life quality interact to influence operator fatigue. It has been established for many operators that restricted sleep and perceived fatigue results from work time demands, and that restricted sleep impedes recovery, but there is much less consideration of recovery during non-work wake time. Such recovery could be assessed by supplementing standard sleep measures with a standard measure of the need for recovery, taken just after and just before work. In addition, the fatigue assessment battery described above could be supplemented by the identification of critical fatigued operator symptoms and behaviours, and used as part of a safety risk management system to trigger countermeasures that prevent operator fatigue affecting performance. It is already possible for schedulers to predict fatigue risks from software parameters based on sleep history, time on task and time of day. However, there is little understanding of the dynamic mutual interactions between poor sleep, health and psychosocial pressures, which will lead to fatigue risks that are poorly predicted by existing software.

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Stiftelsen Norsk senter for samferdselsforskning

Sammendrag:

En vurdering av studier om trøtthet i land- og sjøtransport

TØI rapport 1354/2014
Forfatter: Ross Owen Phillips
Oslo 2014 98 sider

Det finnes mange studier av trøtthet blant transportoperatører i land- og sjøtransport. En måte å vurdere studiene på er ut fra en bred operasjonalisering av trøtthet, noe som forskning viser er nødvendig for å fullt ut å forstå fenomenet. En slik vurdering viser at vår kunnskap om trøtthet i transport er begrenset av at studiene bruker en rekke ulike, men smale konseptualiseringer av fenomenet. Et resultat av dette er at vi vet lite om den relative forekomsten av trøtthet hos ulike transportoperatører. En annen implikasjon er at viktige medvirkende faktorer er blitt oversett, som for eksempel avkobling fra arbeid i fritiden. På samme vis er også viktige effekter av trøtthet oversett, for eksempel sikkerhetsaspekter knyttet til utbrenthet blant operatører. Bedre styring av risikoen knyttet til trøtthet i transport krever at fremtidige studier tar bedre hensyn til de bredere aspektene av trøtthet.

Trøtthet blant transportoperatører som bussjåfører og lokførere er fortsatt en trussel mot sikkerheten i transportsektoren, til tross for at det etter hvert finnes en rekke teknologiske hjelpemidler for å bøte på problemet. For å redusere risikoen knyttet til trøtthet er det viktig å stimulere til en bredere forståelse og anvendelse av forskning på trøtthet i transport. Denne rapporten kan forhåpentligvis være et slikt bidrag i og med at den gir en omfattende presentasjon og vurdering av en rekke studier av årsaker til og konsekvenser av trøtthet blant operatører i ulike transportgrener.

Hvordan bør man forstå trøtthet?

Trøtthet er en abstrakt, diffus og kompleks konstruksjon, med ulike aspekter knyttet til fysiologi, psykologi og prestasjon. Effekten av trøtthet på prestasjon kan være av særlig interesse for ledelse og myndighetsorganer, men en konseptualisering av trøtthet utelukkende med tanke på prestasjon vil være problematisk, ikke minst fordi trøtthet sjeldent manifesterer seg tydelig i prestasjon. På grunn av risikoene som er involvert, vil de fleste transportoperatører være svært motivert for å opprettholde prestasjonsnivået selv om de opplever å bli trøtte. Studier tyder på at de ofte lykkes med det, i hvert fall gjennom et vanlig arbeidsskift. Men forskning viser at det er skjulte kostnader knyttet til det å forsøke å opprettholde prestasjon når man er trøtt, både i form av mer rutinemessig og mindre årvåken utøvelse av arbeidet, og i form av mer langsiktige helsemessige svekkelser på grunn av de økte belastningene involvert.

Disse skjulte eller *latente* svekkelsene kan være skadelige for sikkerheten på måter som er usynlig for operatører og organisasjoner. For å fullt ut å forstå effekten av trøtthet, er det behov for å måle og redegjøre for trøtthet ut fra hvordan det oppleves, hvordan det påvirker fysiologi, og hvordan det kan påvirke prestasjon i både åpenbare og subtile måter. I tråd med dette anvender vi følgende definisjon av trøtthet som grunnlag for å vurdere hvordan studier av trøtthet hittil har operasjonalisert fenomenet:

Trøtthet er en suboptimal psykofysiologisk tilstand forårsaket av anstrengelse. Graden av og dimensjonene ved tilstanden avhenger av anstrengelsens form, dynamikk og kontekst. Anstrengelsens kontekst bestemmes av: Verdi og mening av prestasjon for personen i den aktuelle rollen, hvile- og søvnhistorikk, døgnrytme, psykososiale faktorer knyttet til arbeid og hjemmesituasjon, individuelle trekk, kosthold, helse, fysisk form og andre individuelle tilstander, samt forhold i omgivelsene.

Denne definisjonen innebærer at psykologiske og fysiologiske aspekter må måles for å fullt ut forstå trøtthetstilstanden. For å forstå *prosessen*, må vi karakterisere anstrengelsens form, dynamikk og kontekst, i tillegg til faktiske og latente aspekter ved prestasjonen. Definisjonen plasserer søvnighet som en integrert del av opplevelsen av trøtthet og av prosessene knyttet til trøtthet ("hvile og søvnhistorikk" og "døgnrytme" spiller inn og påvirker anstrengelse). Et interessant spørsmål er hvorvidt og hvordan ulike studier håndterer søvnighet i forhold til en slik bredere forståelse av trøtthet. Studiene vil også bli vurdert i henhold til deres behandling av prosessen bak trøtthet. Det er mange mulige årsaksfaktorer bak trøtthet, og vi ønsker å finne ut hvorvidt noen av disse faktorene har blitt oversett i studiene. Likeledes ønsker vi å vurdere om noen viktige effekter av trøtthet er oversett.

Vurdering av kunnskap ved hjelp av et rammeverk for risikostyring

Et implisitt mål for mange studier av trøtthet er å avdekke risikofaktorer som kan anvendes i risikostyring. For å vurdere i hvilken grad de ulike studiene dekker dette behovet, har vi strukturert studienes resultater ved bruk av et rammeverk for risikostyring knyttet til trøtthet. Dette rammeverket er en utvidet versjon av Dawson & Fletchers (2001) *fatigue-risk trajectory*. Rammeverket er rettet mot ledere og reguleringsmyndigheter, og presenterer fem nivåer for overvåking og mottiltak for håndtering av trøtthet hos transportoperatører:

1. Arbeidstid, arbeidskvalitet, og livskvalitet
2. Faktisk *recovery* fra jobb
3. Selvapportert trøtthet og atferdsmessige symptomer
4. Trøtthetsrelaterte feil
5. Trøtthetsrelaterte hendelser og ulykker

86 studier på operatører som jobber i vei, jernbane og til sjøs

Vurderingen av studiene ble gjort ved å hente inn og gjennomgå felt- eller kartleggingsstudier fra de siste 40 årene som har forsøkt å måle trøtthet hos transportoperatører (vei-, jernbane- eller sjøsektoren). Totalt 86 studier ble vurdert: 24 fra sjøfart, 39 fra veisektoren og 23 fra jernbanesektoren.

De fleste av veistudiene fokuserer på utilstrekkelig søvn, arbeidstid, yrkesrelaterte faktorer og rammevilkår som årsaker til trøtthet. De fleste involverer lastebilsjåfører i langtransport, men det finnes også flere studier av bussjåfører. Trøtthet er ofte operasjonalisert som generalisert søvnighet, selv om flere også vurderer akutt søvnighet eller akutt trøtthet.

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Studier av lokførere fokuserer mer på akutt søvnighet som oppstår på grunn av arbeidstiden. Det er også et større fokus på de mer langsiktige virkningene av trøtthet, og helsemessige konsekvenser av skiftarbeid er spesielt fokusert.

Studier av trøtthet blant sjøfolk har særlig satt søkelys på sammenhengen mellom forskjellige vaktordninger og søvn, spesielt for sjøoffiserer. Sjøstudiene har enten kartlagt situasjonen for et stort antall mannskap, eller vært mer intensive målinger av noen få mannskap på ett fartøy. Generalisert trøtthet er operasjonalisert ved ett eller to av en rekke ulike standardmål. Selvrapporteringer om akutt trøtthet eller søvnighet er også vanlig. Forsøk på å generalisere om forekomsten blant ulike grupper av operatører kompliseres blant annet av at sjøfart er en svært heterogen transportgren. Én studie finner at sjøfolk generelt rapporterer færre trøtthetsymptomer enn det lastebilsjåfører gjør.

Behov for et standardisert målebatteri

Gjennomgangen av forskjellige studier av trøtthet viser at forståelsen av trøtthetstilstander hos operatører i transport er begrenset fordi ulike studier enten bruker skreddersydde mål for å måle trøtthet, eller de benytter én eller to av en rekke forskjellige standardiserte mål. Få studier vurderer ulike dimensjoner av erfart trøtthet. Forståelsen vil kunne bedres hvis anvendte studier bruker et standardisert målebatteri som fanger opp ikke bare akutt og generalisert trøtthet og søvnighet, men også ulike dimensjoner av erfart trøtthet. Et slikt batteri bør inneholde instruksjoner om når trøtthet og søvnighet bør måles i forhold til operatørens arbeidsperioder.

Vi identifiserer fire mål som kan brukes til et slikt batteri: *Epworth Sleepiness Scale*, *Karolinska Sleepiness Scale*, *Swedish Occupational Fatigue Index* og *Samn-Perellis* mål på trøtthet. Dokumentasjon på gjennomsnittlige skårer og andeler av utvalg som skårer over en terskelverdi, vil også kunne bidra til en bedre forståelse og bistå ledere og regulerende myndigheter til å vurdere alvorlighetsgraden av trøtthet i ulike populasjoner. Problemer knyttet til måling av fysiologiske aspekter av trøtthet kunne også blitt bedret ved standardisering, sammen med på naturalistiske observasjoner av operatører i reelle situasjoner. Når det gjelder operasjonalisering av trøtthetstilstanden i studiene som er gjennomgått, finner vi at det ofte ikke skilles klart mellom søvnighet og trøtthet. Framtidige studier bør forsøke å være mer eksplisitte på hvordan man vurderer søvnighet i forhold til trøtthet.

Behov for å ta opp både kvantitet og kvalitet, i og utenfor arbeid

Kvalitative aspekter av arbeidet kan være like viktig som mengden av arbeid (dvs. arbeidstid), og ha avgjørende effekter på søvn og trøtthet. Dermed er det behov for å studere hvordan den psykososiale og fysiske kvaliteten ved arbeidsplassen samspiller med arbeidstiden og påvirker trøtthet. Vi finner også at kvaliteten på livet utenfor arbeidet har blitt oversett som en viktig bidragsyter til trøtthet på jobben. Selv om flere studier i ulike sektorer adresserer rammebetingelsenes betydning for trøtthet, vil komparative studier av operatører i ulike undersektorer kunne illustrere tydeligere effekter av ulike forretningsmodeller og rammevilkår på førertrøtthet.

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Bedre måter å studere effekter på prestasjon

Forbedret rapportering av nestenulykker og ulykker i alle sektorer vil kunne gi bedre forståelse av betydningen av trøtthet. Selvrapporteringer av prestasjonsnivåer kan forbedres ved å standardisere periodene som operatører blir bedt om å rapportere for når det gjelder tilfeller av ekstrem søvnighet, eller at man sovner på jobb.

Mer observasjon av trøtthet i naturalistiske situasjoner vil også kunne bidra til økt forståelse, og økt bruk av driftsparametere, slik som bruk av bremse- og gasspedal, kan være å foretrekke fremfor kunstige kognitive tester. Måten trøtthet påvirker mer komplekse aspekter av prestasjon (for eksempel økt avhengighet på «*mental schemas*») er ennå ikke vurdert i forskningen om trøtthet. Slike studier forutsetter imidlertid at det er mulig å operasjonalisere slike komplekse aspekter ved prestasjon.

Hva trenger vi for bedre å kunne håndtere risiko relatert til trøtthet?

Funnene fra studiene ble også vurdert ved bruk av vårt modifiserte rammeverk for trøtthetsstyring. Denne vurderingen bekrefter at mens arbeidstiden har blitt godt undersøkt, er det likevel behov for å vurdere hvordan arbeidstiden, arbeidsplasskvalitet og livskvalitet *samspiller* i påvirkningen av førertrøtthet.

At arbeidstidsordninger og særlig skiftarbeid har negativ effekt på søvnmengde og -kvalitet, samt at dette hemmer *recovery* fra trøtthet, er godt dokumentert. Imidlertid spiller *recovery* i livet utenfor arbeidet også en viktig rolle når det gjelder trøtthet på jobb. Slik *recovery* kan måles ved hjelp av et standard *need for recovery* mål, etter jobb og før påfølgende arbeidsperioder. Målebatteriet beskrevet over, samt kjente tegn på trøtthetsrelaterte symptomer og atferd, kan brukes som del av risikostyringssystem for å indikere at en operatør er trøtt. Mottiltak kan da tas i bruk for å forhindre at trøtthet går ut over prestasjon. Det er allerede mulig for planleggere å forutsi risiko for trøtthet knyttet til arbeidsskjemaer, ved bruk av programvareparametere basert på søvnhistorikk, tid på jobb og tid på døgnet. Men det er liten forståelse for de dynamiske samvirkende effekter mellom dårlig søvn, helse og psykososialt press. Slike samvirkende faktorer kan gi økt risiko for trøtthet, men dette er risikofaktorer og sammenhenger som eksisterende programvare i liten grad er i stand til å forutsi betydningen av.

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1. Introduction

Human operator fatigue is a serious threat to safe transport by road, sea, rail or air. The problem has led to an abundance of research activity and reports, but there are still few overviews of applied research on human operator fatigue that span different transport contexts. Research studies often focus on a particular branch or sector, and attempts to consider collective research implications for transport safety are either confined to introductory chapters (e.g. Matthews et al., 2012) or assimilated into accounts of fatigue as a problem for workers in general (e.g. Hockey, 2013; Ackerman, 2011; Wilson et al., 2012). There are several reasons to believe that existing reviews would be usefully supplemented by an overview of research studies attempting to measure fatigue in human operators across different transport sectors. Firstly, such an overview would identify any trends in human operator fatigue research specific to certain transport sectors, and serve to highlight whether research methods favored in the study of certain sectors may be usefully applied to the study of other sectors. Secondly, it would help answer whether knowledge gaps in one sector may be filled by research findings from other sectors. Thirdly, identification of those research findings that are consistent across different sectors would help consolidate knowledge about operator fatigue in general transport contexts.

The current report reviews approaches to studying fatigue in human transport operators, according to whether the operators studied work in the road, rail or sea sector. From this review the report identifies any knowledge gaps and lessons that can be learned from research in particular sectors. The rest of this chapter gives some background to fatigue, particularly in relation to its operationalization for the study of human transport operators. This overview outlines the basis of our assessment of the applied study of fatigue in the different transport contexts.

1.1 Assessing fatigue studies

Fatigue is a complex construct. It is abstract, diffuse and multidimensional in character. It has been modelled and measured in many different ways, even within the transport literature (Matthews et al., 2012). The *experience* of fatigue is often seen as central to what needs to be measured, in line with the notion that "the experience of fatigue *is* fatigue" (Noakes and Vlismas, 2012). However, the experience of fatigue itself has several sub-dimensions, including physical, conative, cognitive and emotional dimensions, as well as sleepiness, and in most cases only one or two of these aspects will be measured (Phillips, 2014a). Moreover, the increasing use of broader multidimensional definitions of fatigue reflects an increasing acceptance that it has intractable physiological and performance aspects, in addition to psychological aspects. One way in which to assess approaches to the study of fatigue in different transport contexts is therefore to consider studies according to how they operationalise the construct.

Performance aspects of fatigue may be of ultimate interest in transport safety studies, but conceptualization of fatigue solely in terms of its performance effects will be

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problematic, not least because fatigue often does not clearly manifest itself in performance. Transport operators in particular will be highly motivated to maintain performance in the face of experienced fatigue, and there is evidence that they can do this across the hours of a normal shift (Hanowski et al., 2009). However, there is increasing recognition of the costs of maintaining performance. For example, the operating strategy used by the operator may be simplified or there may be longer-term health decrements because of the increased regulatory effort involved in maintaining performance (Hockey, 2013). A further possibility is that there may be severe decrements in performance of safety tasks that follow on from a primary safety task that an operator has strived to complete. We must also consider the possibility that while a fatigued but motivated transport operator often appears to maintain general performance levels, there may nevertheless be transient moments in which safety performance is very poor. This is illustrated by the work on wake state instability, which describes that the net effect of attentional lapses on cognition in non-rested individuals is instability of performance due to an ongoing "tug-of-war" between the drive for sleep and motivation to remain awake (Doran et al., 2001). The result of state instability is that severe and unpredictable decrements punctuate otherwise safe performance by the operator. Hidden or "latent" performance decrements and the other costs of striving to maintain performance in the face of fatigue are more likely to be revealed in unusual, deviant or demanding situations, with serious implications for safety. Another way to assess approaches to the study of fatigue in different transport contexts therefore concerns the extent to which they consider (i) the extent to which operators are motivated to conserve performance; and (ii) latent decrements to performance.

A further nuance of fatigue that complicates its study is that there is often dissociation between the experience of fatigue and the presence of physiological indicators of fatigue. Thus a person may not feel fatigued even though their performance and physiological levels would indicate otherwise (Craig et al., 2011). Conversely, they may feel fatigued even though physiological indicators are normal. Thus in order to understand the "whole" of fatigue, we also need to measure fatigue physiologically. This is not easy to do when one wishes to assess representative samples of transport workers, especially if they are working. When assessing fatigue studies, we therefore need to ask what knowledge might be missing due to the difficulties of physiological measurement.

1.1.1 What is fatigue?

Reflecting the discussion so far, the current report uses the following "whole" definition of fatigue as a counterpoint against which to compare various attempts at measuring and accounting for fatigue (Phillips, 2014a).

Fatigue is a suboptimal psychophysiological condition caused by exertion. The degree and dimensional character of the condition depends on the form, dynamics and context of exertion. The context of exertion is described by the value and meaning of performance to the individual; rest and sleep history; circadian effects; psychosocial factors spanning work and home life; individual traits; diet; health, fitness and other individual states; and environmental conditions. The fatigue condition results in changes in strategies or resource use such that original levels of mental processing or physical activity are maintained or reduced.

This definition serves to maintain the face validity of any measures derived from it, since reviews find that fatigue is related to exertion in everyday language and by dictionary definitions (Phillips, 2014a). The definition implies that psychological and

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physiological aspects of fatigue need to be measured in order to understand the *state* of fatigue. In order to understand the fatigue *process*, we need in addition to characterise the form, dynamics and context of exertion, in addition to actual and latent performance.

1.1.2 Fatigue and sleepiness

When defining fatigue, we should address how it relates to the more robustly operationalized concept of sleepiness. According to the two-process model of sleep, sleepiness is driven by the combined effect of a sleep homeostasis factor, which increases linearly throughout the day after waking, and circadian factors, which are especially responsible for increasing sleepiness in the early hours of the morning (Borbély 1982). Restricted sleep is a major challenge wherever humans are responsible for sustained transport operations, not least because falling asleep can lead to disaster (Dawson and McCulloch, 2005). Given the seriousness of its implications, some researchers have treated fatigue as synonymous with sleepiness when attempting to improve safety in human transport operators. However, to equate fatigue to sleepiness in this way ignores important task-related or other mental or physical exhaustion, which may be a major threat to safe transport operations without causing operator sleepiness (Phillips, 2014a). Phillips (2014a) includes the following arguments for retaining the concept of fatigue:

1. We wish to understand the effects of sustained work on performance, and sleepiness models say little about this.
2. Vigilance is a central task for all transport operators, and task-related fatigue can have strong effects on vigilance.
3. We are interested in accounting for how cumulative fatigue related to stress and similar energetic constructs may lead to performance reductions over the longer term.

We think therefore it is more useful to include sleep drives (homeostatic and circadian) as a core influence in the fatigue process, and the experience of sleepiness as a core dimension of the experience of fatigue. This line of reasoning is also implied in models of fatigue presented by others (e.g. Williamson et al., 2011). The definition given above is consistent with this approach in that it accounts for sleepiness as an integral component of the experience and process of fatigue. Thus exertion in the face of homeostatic and circadian sleep pressure may increase fatigue beyond that which would have resulted from exertion or sleep drives alone. In addition fatigued states may be revealed in terms of performance decrements in circadian lows, as fatigue becomes too great for the operator to overcome in order to maintain performance. When assessing fatigue research in transport operators we can thus also consider how different studies account for sleepiness in their treatment of fatigue.

1.1.3 Conceptualizing the fatigue process

The lack of models explicitly accounting for the role of sleep drives in fatigue was the basis of a recent model presented by Phillips (2014a). This model, reproduced in Figure 1 below, also accounts for the roles of lower order (subconscious) and higher order (conscious) processes in determining performance, as well as the role of emotions and feelings linked to fatigue in determining its effects on performance.

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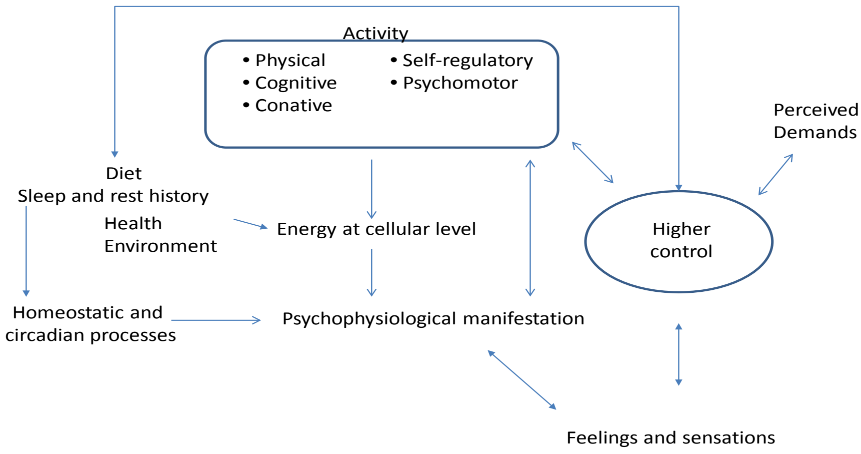

Figure 1. A holistic model of fatigue that accounts for the role of sleep (Phillips, 2014a). Fatigue is not one step in a process, but is described by indices that map the system e.g. the collective state of experiential, physiological and performance/activity (physical, cognitive or psychomotor) indices.

1.1.4 Other ways to conceptualise fatigue

We have said that fatigue studies can be assessed according to the extent to which they account for fatigue in relation to the above "whole" definition, which is a broad treatment of fatigue. This might help understand the limitations of individual studies, or aspects of fatigue that tend to be neglected by studies. There are other ways to conceptualise fatigue that also help our understanding of the construct. For instance, fatigue can be treated as acute, such as that due to severe lack of sleep in the past day or two and/or prolonged work hours (Darwent, et al., 2012), or chronic, such as that due to the long-term presence of workplace or social stressors (Huibers et al., 2003). It may be localised to a specific area of muscle tissue or a generalized feeling (Lützhöft et al., 2007). Depending on its degree and pervasiveness it may be classified as being within a normal or pathological range (Christodoulou, 2012). Depending on task characteristics it may be active or passive (Darwent et al., 2012; Desmond and Hancock, 2001; Saxby et al., 2013). The extent to which studies consider these different forms of fatigue may thus also be of interest to us. For instance, a taxonomy of fatigue measures compiled by Phillips (2014a) suggests that chronic fatigue has been overlooked in the development of occupational survey measures, and it will be interesting to see whether this is also evident in the studies that have been carried out.

1.1.5 Causes of fatigue

We are also interested of course in the extent to which studies consider the broad range of possible influences on fatigue, which are illustrated below in Figure 2. In addition to the effect of work schedules on sleep opportunities (Kecklund, 1995), there will be influences on fatigue from the physical and psychosocial work environment (Demerouti et al., 2001), which may in turn be determined not only by organisational factors, but by broader framework conditions in a particular transport sector (Bjørnskau and Longva, 2009). At the other extreme, individual causes will

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also play a role, such as health status or body-mass index (Braeckman et al., 2011; Phillips and Bjørnskau, 2013), as will factors outside the workplace such as work-family pressure (Demerouti et al., 2004; Phillips, 2014b). In regarding performance effects, Phillips (2014a) concludes that the systemic interaction of sleep history, time of day and time at work or on task should be considered in the context of factors describing the operator's job and non-work/off-duty life. This implies that it is important to consider the extent to which interactions between different causal factors have been assessed.

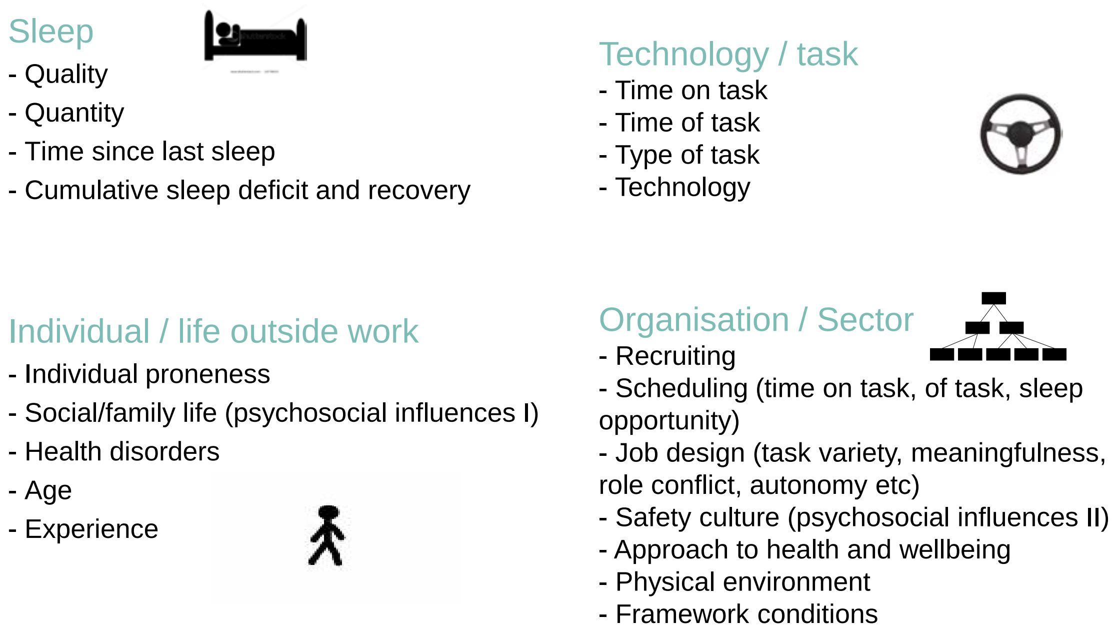

Figure 2. Possible influences on fatigue in the human transport operator, adapted from Phillips and Sagberg (2010). Factors are categorized according to whether they are related to sleep, the person, the organization or are related to the technology or task. Factors will interact across categories to influence fatigue.

1.1.6 Outcomes of fatigue

In assessing fatigue studies in transport, we should also examine whether any safety-related outcomes of fatigue have been overlooked. The vigilance decrement (rapid decrease in performance due to mental underload inherent in monotonous tasks) is well-known in the literature, especially where the operator has little control (Pattyn, Neyt, Henderickx, and Soetens, 2008). This problem is highly safety-relevant and has presumably been surveyed in applied studies. On the other hand simple ways to assess safety-relevant performance may have been overlooked. For instance there are claims that too few studies consider *alertness* across a shift as a key safety-relevant outcome of fatigue (Shapiro et al., 2006). Employee health may also be overlooked, especially in terms of the longer-term safety implications (Phillips and Bjørnskau, 2013). An interesting question is therefore to what extent studies have captured all of the safety implications of fatigue, in addition to its causes.

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The following conclusions from an attempt to link fatigue effects to actual safety duties, by Phillips (2014a), can also be considered when assessing fatigue studies to date:

- Many different types of transport operators are challenged by task underload, i.e. having to perform a vigilance task under unstimulating, monotonous conditions, and this often occurs at times of day when sleep drives are at their highest, e.g. 0400 h to 0600 h. This may present severe problems in terms of vulnerability to sleepiness and maintenance of cognitive task performance.
- Task overload may also be a problem for some operator roles. For any operator, fatigue may pose a particular threat to skill-based task performance, in terms of increase risk of slips and lapses (Reason et al., 1990; Stanton and Salmon, 2009).
- There are safety risks from the influence of fatigue on complex faculties that allow operators to be mindful about emerging situations, assess a range of possibilities, and act on emerging situations. In such cases, fatigue would not only influence simple attention and reaction time, but immediate priorities, expectations, the current world model, and access to and salience of knowledge and previous experience. Effects on decision-making and memory may also be important in this regard.

1.2 Basis of study assessment

Given the many aspects of the fatigue state and process, along with its many possible causes and effects, one must inevitably be selective when studying fatigue in human transport operators. A general aim therefore is to consider through a review of representative studies, which aspects, causes and effects have been considered by the different studies, and which have been overlooked. Finally, we also wish to assess research studies in terms of methodology used. In particular we are interested in which populations are in focus, whether they are representative, and whether they are the ones most at risk for fatigue or ones whose behaviour has the greatest implications for safe transport operations.

Thus our strategy for the assessment of fatigue studies can be outlined as follows.

When measuring the fatigue state:

1. Is the experience of fatigue state itself measured along several dimensions?
2. Do they consider both psychological and physiological aspects of the fatigue state, and possible dissociation between these states?
3. Do they account for sleepiness explicitly in relation to fatigue?
4. Are established measures of fatigue employed that are known to be valid and useful for occupational samples, and which would allow for useful comparisons among different operators, and with other occupational samples?
5. Which populations are in focus, are they representative, and are they the ones that are most at risk for fatigue, or whose behaviour has greatest implications for safe transport operations?

When considering the causes of fatigue:

6. Do the studies account for the complete system of various interacting fatigue causes, in particular actual sleep history, time of day and time-on-task, but also organisational /sectoral influences, environmental influences, individual traits and states, and the influence of factors anchored in life outside work?

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When considering the outcomes of fatigue:

7. To what extent is safety-relevant performance considered?
8. Do the studies consider a range of performance implications, particularly attention problems in low control/underload situations, but also mode errors and effects on fatigue of more complex faculties, including increased reliance on mental schemas?
9. Do they consider motivation and latent performance effects, including momentary decrements or decrements to the performance of tasks following on from the primary task? In particular, do they consider the safety implications and longer-term health costs of chronic fatigue?

Answering the above questions would also help answer whether studies operationalize fatigue in relation to the broad "whole" definition above.

1.3 Assessing knowledge gaps and lessons learned

A comprehensive overview of fatigue-related safety risks confirms that human fatigue is linked to an array of performance decrements and negative safety outcomes (Williamson et al., 2011). Given this concern, applied studies of fatigue seek to identify how factors related to people (operator, psychosocial/organisational and sociopolitical contexts) and situations (time-related factors, physical environment) influence fatigue in real work situations. Some applied studies also go on to consider the effects of fatigue in terms of safety behaviour, near misses and accidents. In Section 1.1 we explained how we will assess the methodology of these studies, particularly as regards how they treat the concept of fatigue, how they measure the fatigue state, and which of the various influences on and outcomes of the dynamic process of fatigue are considered. Put simply, this first part of the review will tell us whether existing studies are good enough.

In a second aspect of the review, however, we also wish to summarise findings of the studies on the prevalence, causes and effects of fatigue in human transport operator. Of course this second part of the review will be tempered somewhat by the first: aggregation and generalization of findings may be prevented by the different ways in which fatigue has been operationalized. However, the hope is to be able to draw conclusions about fatigue in different types of transport operator and determine whether there is knowledge that can be consolidated across sectors, or applied from one sector to another.

1.4 Assessing implications for practice

The third main issue addressed in this report concerns how studies have informed practice in particular sectors. Recent times have seen advances in the management of fatigue-related risks, through dedicated programmes for fatigue management or by better accounting for fatigue as a risk to be integrated into safety risk management systems (Smith et al., 2007; Phillips and Sagberg, 2010). One way to assess the extent to which knowledge has been gathered in areas corresponding to different levels of fatigue risk management is to structure knowledge according to a so-called fatigue-risk trajectory given in Table 1 (Dawson and Fletcher, 2001).

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Table 1. Modification of Dawson and Fletcher's (2001) fatigue-risk trajectory to account for broader fatigue. For explanation see text.

Risk level	Original fatigue-risk trajectory	Trajectory modified to account for broader fatigue
1	Sleep opportunity, average sleep for occupational group	Work time, work quality, non-work life quality
2	Actual sleep obtained	Actual recovery from work
3	Behavioural symptoms	Reports of fatigue and behavioural symptoms
4	Fatigue-related errors	Fatigue-related errors
5	Fatigue-related incidents and accidents	Fatigue-related incidents and accidents

The idea is that fatigue is best tackled by monitoring and measures at all levels of the trajectory. Given that the original trajectory was designed to focus solely on sleep-related fatigue, it has been modified in Table 1 to account for our broader treatment of fatigue.

The first level in the modified version describes the "framework conditions" for operator fatigue – organisational and other life factors that together determine the level of fatigue an operator is exposed to. Work time describes the formal length and timing of work periods, breaks and rosters. Work time determines time left for life outside work (non-work time), including sleep opportunity. As Dawson and Fletcher (2001) suggest, real sleep opportunities afforded by work time can be approximated by measuring average sleep lengths for the occupational group of interest. Work quality describes the psychosocial and physical nature of work, including aspects of work environment. Non-work life quality describes psychosocial and physical nature of life outside work hours, and may include aspects of the living and sleeping environment. We consider that these factors are also important in determining levels of fatigue at work.

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The second level in the modified trajectory describes the actual recovery from work. This is described not only by actual sleep quantity and quality, but also by actual breaks taken while at work, and work recovery during non-work wake time. The latter can be assessed, for example, by determining the need for recovery after work and before the next work period. Recovery may be physical or psychological. Level 3 has been extended to include in addition to behavioural symptoms of fatigue, which can be used as triggers for countermeasures, reports of fatigue by operators, which can also be used to assess risks and trigger countermeasures. Levels 4 and 5 describe fatigue-related errors and incidents and accidents as originally described by Dawson and Fletcher (2001).

The modified trajectory described by Table 1 will be used in this report to give a brief assessment of how existing knowledge informs practice in terms of fatigue risk management.

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2 Aims

This study aims to give an overview of selected research studies investigating human transport operator fatigue in the road, rail and sea sectors.

In particular it aims to address the following issues:

- Are the studies good enough, i.e. do they measure fatigue in the most appropriate way and rely on models that are optimally meaningful in relation to the risks?
- Are there any gaps in our knowledge of operator fatigue in particular transport sectors, or across those sectors?
- What do studies from different sectors tell each other?
- What do studies say about the way fatigue risks should be managed?

2.1 Report structure

The first of the above aims is achieved by summarizing study methodology according to sector, in terms of contributing factors and fatigue-related outcomes addressed; populations studied and how they were sampled and tested; and how fatigue is operationalized, with particular regard to sleepiness. The second, third and fourth aims are achieved by reviewing within and across sectors research studies according to their findings on the prevalence, causes and outcomes of fatigue.

The report is structured by first presenting a descriptive review of study methodology and study findings for each sector in turn: for the road sector in Section 4.1, the rail sector in Section 4.2, and the maritime sector in section 4.3. Section 5 then presents an assessment of studies within and across sectors, in terms of their treatment of fatigue and suitability of methodology; knowledge gaps; lessons to be learned; and implications for practice. The conclusions are then given in Section 6. We begin in the next section by outlining our approach to the literature review.

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3 Method and scope

3.1 Strategy

At the outset of the project we employed the following strategy to answer the questions described in Section 1:

1. Identify international studies that have attempted to survey and describe fatigue status of human transport operators working in land and sea sectors.
2. Select studies according to the criteria below.
3. Review studies by identifying:
    - i. type of study
    - ii. population(s) studied
    - iii. fatigue and sleepiness measures, operationalisation
    - iv. any causes and outcomes measured
    - v. findings on causes, prevalence and effects
    - vi. challenges encountered
4. Use results of this review to generate a descriptive overview of fatigue research studies in each sector, and to answer the questions laid out in the aims.

3.2 Study inclusion criteria

The following were the criteria for study inclusion:

- Select only field or questionnaire studies attempting to measure fatigue in human transport operators working in the road, rail or sea sectors.
- Selected studies must include a measure of fatigue in terms of experience, physiology or performance i.e. in line with definition in Section 1.1. The studies may or may not include measurements of its causes and safety-related effects.
- Selected studies must be less than 40 years old.

These criteria excluded the following types of studies:

- Experimental studies using fatigue as a measure, in particular lab and simulator studies (e.g. Otmani et al., 2005).
- Studies seeking to establish a measure of fatigue (e.g. Häkkänen et al., 2012)
- Studies based on interviews or focus groups aiming to induce the causes of fatigue (e.g. Bhatt and Seema, 2012);

Such studies usually involve small numbers and usually do not inform about the causes, state or effects of fatigue in the working transport operator. Although interesting, analyses of schedules or sleep activities were also omitted if they did not include a measure of fatigue e.g. (Kecklund, Åkerstedt et al., 1999; Moreno et al., 2003).

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3.3 Study retrieval

Studies were retrieved in three main ways.

1. By scanning TRID and Google Scholar database searches generated using the following search terms:

   Fatigue + survey + truck driver; Fatigue + survey + professional driver; Fatigue + survey + train operator; Fatigue + survey + train operator; Fatigue + survey + watchkeeper; Fatigue + survey + marine pilot; Fatigue + survey + human + shipping; Fatigue + survey + bridge crew.

   In the case of Google Scholar, we took the first five pages of hits, while in the case of the TRID database, all results were scanned.

2. An appeal was made via the internal email network of the Working Time Society (Committee on Shiftwork and Working Time, of the International Commission on Occupational Health) for studies which matched the criteria in Section 1.2.

3. The authors own literature database[1] was scanned for studies which matched the above criteria.

3.4 Caveat

While as many studies as possible have been included, this is not an exhaustive review of all studies collected using the above criteria. We prioritized studies based on quality, but did not document this systematically, and inevitably convenience played a minor role in which studies were included. We do not consider, however, that this detracts from the implications of our findings. In the case of the rail sector, fewer studies were available, and we consider that numbers included as representative of available studies in each sector.

[1] Available on request from rph@toi.no

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4 Description of studies

We retrieved 86 studies on fatigue in human transport operators. These consist of 24 from shipping, 39 from the road sector and 23 from the rail sector (see Appendix for a list of individual studies.) This section contains a summary of the studies according to whether they were studies of operators in the road, rail and sea sector, respectively. For each sector, we give background to the operator role, followed by a review of what has been studied altogether, in terms of contributors to fatigue, fatigue-related outcomes and operator populations. We then review approaches to data collection and sampling, followed by a consideration of how fatigue is operationalized by the studies in the sector in question. Finally, we give collective findings on the prevalence, contributors and outcomes of fatigue for that sector. In the following section (Section 5) we assess the studies within and across sectors, according to the research questions identified in Section 1.

4.1 Road

Relative to other transport sectors, a large number of research studies have been carried out to assess fatigue in road operators, especially for truck drivers. Fatigue in truck drivers poses a great risk to other road users, due to a combination of monotony due to long distances, demanding working hours, and the large weight and/or hazardous nature of the loads that they carry. Fatigue in bus drivers is also often a subject of study, since bus drivers work challenging shift patterns, drive heavy vehicles and carry many passengers. Some can also drive long distances. Despite a focus on monotony and driving at night, there appears to be increasing recognition that local or regional truck or bus driving during the day can also be fatiguing, not least due to the need to negotiate intense traffic and stresses associated with carrying out multiple passenger drops or deliveries according to schedule in a busy city (Enehaug and Gamperiene, 2010). Taxi drivers are undoubtedly also vulnerable to fatigue, since they work irregular hours at all times of the day and night, and have long periods of waiting punctuated by operative periods (Dalziel and Job, 1998). There is also increasing recognition that those who must use a company or private car during work hours can also suffer from fatigue, although they are outside the scope of the current review.

4.1.1 Contributors and outcomes studied

Factors contributing to fatigue that have been studied can be divided into five main groups:

- Sleep and schedules. These are sleep-related factors described by shift schedules, sleep opportunities, sleep quantity, sleep quality or coping with sleep (e.g. Häkkänen and Summala, 2000a; Sabbagh-Ehrlich et al., 2005; Baas et al., 2000; Braeckman et al., 2011; Williamson and Friswell, 2013; Baulk and Fletcher, 2012; Hanowski et al., 2011; Ursin et al., 2009).
- Other occupational factors and framework conditions, e.g. psychosocial work factors (including perceived workload, demands, control and support), cargo

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type, economic pressures, regularity of time or type of employment contract, employer-employee relations and perceived colleague norms in relation to fatigued driving, break times etc. (Crum and Morrow, 2002; Åhsberg, 2000; Adams-Guppy and Guppy, 2003; Sabbagh-Ehrlich et al., 2005; Williamson, Feyer, and Friswell, 1996; Baas et al., 2000; Feyer and Williamson, 1995; Williamson et al., 1992; Williamson and Friswell, 2013).

- Health/dietary habits, physical activity, health status and sleep disorders (Asaoka et al., 2010; Carter et al., 2003; Häkkänen and Summala, 2000a; Mackie and Miller, 1978; McCartt et al., 2000; Sabbagh-Ehrlich et al., 2005).
- Social activity or factors related to life outside work (e.g. Crum and Morrow, 2002).
- Demographics e.g. age, socio-economic status, educational level (e.g. Mello et al., 2000).

Most studies include two or more of the four main types of contributing factors listed above. Factors most often studied appear to be those in groups 1 and 2. The most comprehensive studies take account of a range of occupational conditions, and often include both subjective and objective measures of sleep quantity and quality (e.g. Braeckman et al., 2011; Baulk and Fletcher, 2012). They can also include surveys of the fatigue management strategies used by drivers in relation to their fatigue.

Outcomes of fatigue that have been studied are various and include drowsy driving (National Sleep Foundation, 2012), sleeping at the wheel (Sabbagh-Ehrlich et al., 2005), real-world driving performance (Mackie and Miller, 1978; Battelle Human Factors, 1996), task-related psychomotor performance (Charlton and Baas, 2006) or other cognitive tests (Williamson et al., 1996), fatigue-related critical incidents while driving (Hanowski et al., 2011), self-reported effects of fatigue on driving performance (Friswell and Williamson, 2008), burnout (Sluiter et al., 1999), shiftwork disorder (Asaoka et al., 2010) or fatigue-specific health symptoms (Karimi et al., 2013). Some outcomes are more difficult to attribute solely to fatigue as they are often related to other energetic constructs such as stress. Examples are near miss or accident history (Adams-Guppy and Guppy, 2003; Carter et al., 2003; Crum and Morrow, 2002), blood pressure, blood composition (Moreno et al., 2004), health status (Carter et al., 2003), psychosomatic complaints (Sluiter et al., 1999) and rule-breaking (Williamson et al., 2001).

4.1.2 Populations studied

Most studies involve truck drivers and most of the listed influences and outcomes considered apply to truck driver studies. There has been consideration of light/short haul drivers versus long haul drivers in Australia (Friswell and Williamson, 2013). Studies on bus and coach drivers include Mackie and Miller's (1978) seminal study on both bus and truck drives, and a study on the effects of task-related stressors on physiological and subjective measures of anxiety (Raggatt and Morrissey, 1997). There has also been a study on the effect of recent and longer term working patterns and psychosocial work factors on sleep quality on fatigue and its associated effects on psychosomatic complaints and emotional exhaustion in bus drivers (Sluiter et al., 1999), as well as a study on the effects of impaired sleep on vigilance and accident rate (Karimi et al., 2013). There would appear to be fewer studies that directly assess fatigue in taxi drivers (Dalziel and Job, 1998). In addition to driver surveys, interesting data has also come from surveys of the national population which capture occupational type (National Sleep Foundation, 2012).

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4.1.3 Data collection and methods

Since professional drivers have a mobile workplace, collecting data can be a challenge. Strategies used by researchers to access drivers are as follows:

- Surveys/interviews of drivers at roadside rest stops, control stations, fuel stops, depots, ferry terminals, ports or at base of larger haulage companies or bus terminals (Moreno et al., 2004; Charlton and Baas, 2006; Williamson and Friswell, 2013)
- Surveys/interviews at training or other event organized by union or employer (e.g. Häkkänen and Summala, 2000a)
- Mail survey using normal post or internal mail systems (Carter et al., 2003; Sluiter et al., 2003)
- Surveys distributed at strategic points by researchers, e.g. fuel stations, taxi ranks, depots (e.g. Dalziel and Job, 1997)
- Survey cascaded down through organizations (Crum and Morrow, 2002)
- Use of instrumented vehicles or continuous measurement of driver physiology or behaviour while driving (Hanowski et al., 2011; Kecklund et al., 2001)
- Drivers asked to fill out logbooks on work and rest days, and at different times across a shift while in or out of vehicle (Williamson et al., 1996)
- Drivers recruited for overnight measures (Karimi et al., 2013)
- Self-report survey distributed at health screening service (Ursin et al., 2009)

Surveys are by far the most common way to collect data on fatigue. Where they are given, survey response rates appear to vary widely, but our impression is that personal contact and involvement of an employer, union or interest group is beneficial to survey response, especially if no researcher is present when the survey is received. Interestingly, in one study two-thirds of drivers opted to fill out a self-report survey rather than go through an interview at a truck stop (Williamson and Friswell, 2013). Driver logs are especially useful in capturing aspects of the driver's everyday work that may influence fatigue, such as waiting around or loading and unloading activities, in addition to driving (Soccolich et al., 2013). Data from naturalistic driving studies can also be a very useful complement to survey data (Hanowski et al., 2011).

4.1.4 Operationalization of the fatigue state

Many researchers fail to give explicit accounts of how they have operationalized fatigue. One way to consider how fatigue has been operationalized by individual studies is instead to consider the particular measure(s) of fatigue employed. Interestingly, 15 out of 39 studies employ the Epworth Sleepiness Scale (Epworth Sleepiness Scale) (Johns, 1991), which asks respondents to rate their daytime propensity to fall asleep in different situations, such as while travelling a passenger in a car, or while watching a film at the cinema. The scale does not define a time period over which the respondent should rate their sleepiness in various situations, but is in any case more a measure of chronic than acute sleepiness. One advantage of the Epworth Sleepiness Scale is that since it is the most commonly used measure of fatigue, it allows for comparison across different populations or in different conditions. Several studies employ Epworth Sleepiness Scale as the main or only measure of fatigue (e.g. Asaoka et al., 2010; Braeckman et al., 2011; Carter et al.,

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2003; McCartt et al., 2000). This reflects that it is not uncommon that researchers' confine fatigue to sleepiness. Even when sleepiness is in focus, however, there is a need to employ supplementary measures, i.e. the Epworth Sleepiness Scale alone will not capture acute problems that the driver may be experiencing. For instance, a driver who may not have been at all fatigued in the last few months, but who may be experiencing severe acute fatigue due to challenging life or work event, will not be fatigued according to the Epworth Sleepiness Scale. In addition, while the Epworth Sleepiness Scale measures sleepiness in general life situations, it says little about sleepiness at work or while driving. Indeed, the Epworth Sleepiness Scale may be best suited to measure the longer term, latent effects of working on a restricted sleep schedule. Given these limitations, several studies complement Epworth Sleepiness Scale with other measures, often a measure of momentary (acute) sleepiness, such as the Stanford Sleepiness Scale or the Karolinska Sleepiness Scale (Karimi et al., 2013). Häkkänen and Summala (2000) account for sleepiness on the job in addition to using the Epworth Sleepiness Scale.

Operationalising fatigue as sleepiness may be more appropriate for those particularly interested in the effects of sleep problems on fatigue. For instance, Carter et al. (2003) assess several sleep-related contributors to fatigue, and it makes sense to relate this to the propensity for sleep during the day. Further argument for confining fatigue to sleepiness is that subjective measures of sleepiness may be complemented and validated with objective measures, such as the multiple latency sleepiness test (MLST) or observer ratings of drowsiness prior to critical incidents recorded by naturalistic studies (Santos et al., 2004; Hanowski et al., 2011; Soccolich et al., 2013). In addition, one study finds a high correlation between sleepiness over the longer term (Epworth Sleepiness Scale) and a momentary, broader measure of fatigue, adapted from the USA Air Force's Crew Status Survey, where the respondent scores how they feel from fully alert (=1) to completely exhausted (=7) (Charlton and Baas, 2006). Despite this, many studies recognise that fatigue is a broader concept than mere sleepiness. Sluiter et al. (1999) and Feyer et al. (1993) both consider fatigue to include in addition to feelings of sleepiness, those of drowsiness, tiredness, poor concentration, cognitive slowness and inability to sustain attention. Likewise Adams-Guppy and Guppy (2003) consider in addition to sleepiness, that driving while tired and being unable to concentrate are important outcomes of fatigue in their own right.

Studies interested in documenting the acute effects of shifts or time-on-task are more prone to employ measures of acute sleepiness or fatigue, such as the Stanford Sleepiness Scale, bipolar visual analog scales to measure fatigue or the acute fatigue scale of Pearson and Byars (1956) (Milosevic, 1997; Williamson et al., 1996; Mackie and Miller, 1978; Baulk and Fletcher, 2012). One of the most well developed measures of momentary occupational fatigue is the Swedish Occupational Fatigue Index or SOFI (Åhsberg et al., 1997). Even though it is not in widespread use, research shows that it is psychometrically robust in several languages (González Gutiérrez, Jiménez, Hernández, and López López, 2005). It also generates occupationally dependent fatigue profiles (Åhsberg et al., 2000). For instance, compared with locomotive drivers, firemen, cashiers and teachers, bus drivers score highest or next highest on the fatigue dimensions of "sleepiness", "lack of motivation", "physical discomfort" and "lack of energy", but score relatively low on "physical exertion".

Some studies measure stress-related aspects of fatigue, for instance by measuring it using the State-Trait Anxiety Inventory (Raggatt and Morrissey, 1997; Mello et al.,

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2000). This reflects an interest in drivers working stressful shifts, such as city bus drivers. Others emphasise the manifestation of fatigue as the need for recovery from work (van Veldhoven and Broersen, 2003) (Sluiter et al., 2003), which would appear to be a good way to tap into fatigue that builds up over the course of a working day.

Several studies create their own measure of fatigue, often based on a single question item (Moreno et al., 2003; Baas et al., 2000; Williamson et al., 1992; Williamson et al., 2001), or ask about the frequency of driving while tired (Adams-Guppy and Guppy, 2003) or fatigued (Sabbagh-Ehrlich et al., 2005). Better studies of this type operationalize fatigue for the respondent rather than letting respondents define it for themselves, e.g. "*By fatigued we don't just mean feeling drowsy or sleepy. We also mean being tired, lethargic, bored, unable to concentrate, unable to sustain attention and being mentally slowed.*" (Williamson et al., 2003). Nevertheless these studies appear to consider that fatigue and/or tiredness are terms that most people understand, and can perceive and report reliably. Results based on responses to these items must be interpreted carefully, since little evidence is available for the psychometric robustness of one-off, single item measures of fatigue.

Several studies complement subjective measures of fatigue with objective measures such as heart rate variability or EEG measurements (Diez et al., 2011).

4.1.5 Findings

This section presents an overview of study findings according to whether they concern the prevalence of fatigue among professional drivers, contributors to fatigue or the effects of fatigue.

Prevalence

As mentioned earlier, the Epworth Sleepiness Scale measure of daytime sleepiness is the most common way to measure fatigue by the studies included here. The total Epworth Sleepiness Scale score is the sum of 8 item-scores and can range between 0 and 24. The higher the score, the higher the person's level of daytime sleepiness. Data from Australia show that "normal" adults (N = 72) who do not have evidence of a chronic sleep disorder (including snoring) have a mean Epworth Sleepiness Scale score of 4.6 (95 per cent confidence intervals 3.9 – 5.3) with a standard deviation of 2.8 and a range from zero to 10. The normal range defined by the 2.5 and 97.5 percentiles is also zero to 10 (Johns and Hocking, 1997). Maycock (1995) reports average Epworth Sleepiness Scale score for a sample of UK truck drivers of 5.7, but higher levels have been found among other truck driver samples, ranging from 6.1 to 7.8 (Baas et al., 2000; Charlton and Baas, 2006; Braeckman et al., 2011), with the higher end values being reported for Australian short- and long-haul drivers (Howard et al., 2004; Williamson and Friswell, 2008; Friswell et al., 2006). Carter et al. (2003) found that professional drivers had a greater average Epworth Sleepiness Scale score (7.1) than a corresponding control group (6.7). A systematic comparison of absolute scores, accounting for varying contexts and standard deviations, may be useful, but a more informative way of reporting the Epworth Sleepiness Scale may be the percentage of drivers in the sample who score above 10, indicative of elevated general sleepiness and increased risk of sleep disorder (Johns, 1991). In a sample of Australian truck drivers, 18 per cent of drivers were found to have an Epworth Sleepiness Scale above 10, with other studies indicating that as many as 1 in 4 score over 10 (Williamson and Friswell, 2008). Daytime hypersomnolence in a sample of

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Swedish drivers was diagnosed as present in 26 per cent of the sample (Karimi et al., 2013).

One-off measures of fatigue using customized questions are also common (e.g. *How often is fatigue a problem for you?*). As we have seen the word “fatigue” may or may not be operationalized for the respondent, and the word “fatigue” may also be replaced by words such as “alertness” or “tiredness”.

The following are examples of ways in which fatigue rates are reported using one-off measures:

- Häkkänen and Summala (2000b) report that 40 per cent and 21 per cent of long- and short-haul have problems staying alert on 20 per cent of their drives.
- 7 per cent of drivers in Adams-Guppy and Guppy’s (2003) study reported driving fatigued at least quite often, 21 per cent at least sometimes.
- Despite 81 per cent starting trip feeling fresh, 45 per cent of drivers develop fatigue during a trip (Williamson et al., 2003).
- In response to "How tired are you after shift?", 55 per cent reported being tired or very tired (Williamson and Friswell, 2008).
- 38 per cent of participants experienced fatigue at least once a week while driving for work (Friswell et al., 2006).
- Frequency of driving "tired" has also been used in several studies (Crum and Morrow, 2002) (Mackie and Miller, 1978; Williamson et al., 1994).

The usefulness of these measures beyond the comparisons within the individual studies in which they are used is uncertain. We cannot say whether even large differences between studies using these measures are due to differences in the measure used or real differences in the populations from which the sample or drawn.

Objective measures of sleepiness are more amenable for comparison across studies, but there are often challenges related to their use, which has restricted their application in studies. This is particularly true of MSLT (Santos et al., 2004). A simpler way to collect figures on safety-relevant sleepiness is to ask respondents to report on the number of times they have slept behind the wheel over a defined period (usually 12 months). This measure is considered further under fatigue “Outcomes” below. An alternative promising objective measure of fatigue is naturalistic observation, which should become increasingly attractive as technology becomes more accessible and affordable. The findings based on this method so far are alarming. For instance, from observer ratings based on over 4000 h of driving time, it was found that drivers drove in a drowsy state for 5 per cent of the time (Wylie et al., 1996). A naturalistic observation of long and short haul truck drivers in the US found that 3.5 per cent of driving time were spent in a drowsy state, during which road attention and monitoring was significantly reduced (Barr, Yang et al. 2005). Such ratings may not only form the basis of more robust comparisons of fatigue between samples, but also be more convincing to managers and regulators than subjective measures, especially when the psychometric robustness of the latter is in question.

Finally, we note that several studies compare shares of drivers who view fatigue as a problem for their industry and for themselves. For instance Sluiter et al. (1999) report that 62 per cent in their sample thought fatigue was a big problem in their sector, while 23 per cent thought it was a big problem for them personally. Alrukaibi and Koushki (2008) report similar findings. However, 21 per cent of Baas et al.’s (2000) sample rated fatigue as often a problem for other drivers, and 8 per cent for

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themselves. Thus, while we are unsure about absolute figures, it seems that many drivers rate fatigue as a serious problem for other drivers or for the industry than for themselves, and thus drivers may underestimate the extent to which fatigue is a problem for them.

Contributors

We now consider findings on contributors to fatigue, in line with our review in Section 3.1.1, i.e. organisational, occupational/sector conditions; sleep-related factors; activity, diet and health; social factors outside work; and demographics.

Organisational and sectoral conditions

Task effects are worrying given the extent to which truck, bus and taxi drivers have been found to work in various countries. The US National Sleep Foundation (2012) survey concluded that the average shift lengths of truck and taxi driver was significantly greater than for other occupations. Studies in other countries find long duty times for truck drivers, e.g. the average length of the preceding duty in a New Zealand sample was 10.5 h (Charlton and Baas, 2006). In a study of Israeli truck drivers, 38 per cent had worked over the 12 h legal limit the day prior to interview (Sabbagh-Ehrlich et al., 2005). In Europe, 13 per cent of long-haul drivers have been found to have shift lengths exceeding EU regulations on driving time (Häkkänen and Summala, 2000b). Some bus drivers may work shorter average shifts than control groups, but in these cases split shifts are implied, i.e. two separate shifts on same day (National Sleep Foundation, 2012). Split shifts may present unique challenges in terms of driver fatigue, not least because they may effectively extend the length of the working day (Phillips and Bjørnskau, 2013).

Truck and bus drivers are less likely than most other occupations to work the same schedule each day, and when they do work same schedule, less likely to start between 0600 and 0900 h (National Sleep Foundation, 2012). Truck drivers spend more hours working per week than most other occupations, including bus and taxi drivers. Perhaps the most alarming results come from long-distance truck drivers in countries with large distances. A study by Williamson et al. (2003) was of a sample of drivers whose last average trip length was 1700 km, and had driven an average of 19 h in a 35 h period. 71 per cent of the drivers did night work, and a quarter of trip working hours completed from 0000 to 0500 h. 20 per cent drivers also did loading work. The average sleep length before a trip was 5.75 h, with an additional 2.5 h of rest. Other New Zealand studies find that that the average length of a working day for its sample of truck drivers was 12 h, with an average week of 5.4 d. The length of the "last sleep" was on average 7.2 h, and there had been an average of 1.2 h of physical work in last 24 h, and 25 minutes of desk work (Baas et al., 2000; Charlton and Baas, 2006). In a US sample, the length of the average shift was 9.4 h, with half starting shift after 11am (Adams-Guppy and Guppy, 2003). The average distance driven each day was 209 km, but could be as high as 900 km. In smaller countries maximum trip lengths are considerably less (Sabbagh-Ehrlich et al., 2005; Braeckman et al., 2011).

Most professional drivers are thus in effect asked to carry out a task that is uniform in nature, over a prolonged period, day after day. Referring back to our definition in Section 1.1, we would naturally expect them to become fatigued. Indeed subjective fatigue has been found to increase across trips, with only partial recovery after a one-hour break mid-trip (Mackie and Miller, 1978). Mackie and Miller (1978) also found evidence that fatigue accumulates across successive work days, in their case across six days. Mackie and Miller's (1978) study was a follow up to an earlier study, which had

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collected data on fatigue in routine bus and truck operators in the US, i.e. drivers with regular schedules, employed by common carriers and with little physical work (Harris and Mackie, 1972). In this earlier study evidence was found for degradation in truck driver status with time on the road, in terms of physiological activation (change in heart rate), loss of alertness (change in heart rate variability) and decrements in tracking while driving. Fatigue development during long distance trips has also been found for Australasian samples of truck drivers, and none of different regimes studied were found to prevent it developing (Williamson et al., 1996). The extent to which this happened was found to be related mostly to pre-trip fatigue levels, which were higher for those on staged relay trips. Fatigue was indicated by the results of a cognitive performance test, although results for arousal and driving performance measures were less conclusive (see Outcomes).

Raggatt and Morrissey (1997) also investigated wear and tear on the job, in Australian truck drivers. Various self-reports were collected at four set times in a driver's shift, and compared with measures taken for the same driver at the same time of day on an off-duty day. All stress measures were elevated during the shift, with decelerated arousal from 9th to 12th hour (reductions in heart rate and self-reported arousal). The latter was claimed to be indicative of release of tension due to anticipated end of shift, which may have important safety implications if deactivation is a trigger for the onset of fatigue. Milosevic (1997) investigated task effects in different types of bus and truck driver, monitoring reaction time and subjective fatigue in real time in response to shift progression. The largest changes in visual reaction time variability and change in subjective evaluation of fatigue were found for city bus drivers. Interestingly, 48 per cent of truck drivers versus 84 per cent of dumper drivers, said fatigue signs appear after 4-6 h driving. The particular operationalization of fatigue may be key to this difference: if it had been operationalized as drowsiness and sleepiness, fatigue may have been more dominant among tuck drivers who are subjected to longer hours of monotonous driving (Häkkänen and Summala (2000a). Finally, shift length and number of driving days per week were each related to psychomotor performance in a sample of New Zealand drivers, along with the amount of rest and sleep (Charlton and Baas, 2006).

A US study found that trailer configuration affects lane performance, subjective workload and subjective fatigue and physiological state, depending on the demands of driving it (Battelle Human Factors, 1996). There were also configuration-related carryover effects to the next day's driving. The study concluded that some triple-trailer drivers would be expected to experience dangerous workload levels, but this would vary depending on the individual driver. Differences in psychomotor performance have also been found according to cargo type. A greater share of drivers carrying logs, stock and refrigerated loads failed a psychomotor test, than those carrying out general/local deliveries or other line-haul functions (Charlton and Baas, 2006). These differences may reflect that the former loads are carried over long distances *and* are subject to strict delivery deadlines. However, a separate study finds that longer daily work hours, higher subjective load and percentage of freight movements from customers to depots each explained unique variance in frequency of fatigue experiences (Williamson and Friswell, 2008; Friswell et al., 2006). Thus it is not only the irregular work schedules that can be fatiguing (Mackie and Miller, 1978), and those on regular schedules may have been overlooked by research, at least in the context of light/short haul drivers. Indeed on comparing findings from short/light haul drivers (from a national Australian survey in 2004-2005) with those from long distance heavy vehicle drivers (from a national Australian survey in 1998), Friswell

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and Williamson (2013) found that equal shares of drivers in the two groups experienced fatigue as a problem. However, the groups had different work-related contributors, effects and coping strategies. Light drivers worked relatively regular but long day hours with few breaks and high exposure to urban traffic in less comfortable vehicles. For them, long hours, insufficient sleep, inadequate sleep before work, insufficient breaks, and heavy traffic were the most important contributors of fatigue. Heavy vehicle drivers also worked long hours, but at all times of day and night. Unlike light vehicle drivers they highlighted waiting and dawn driving as the most important contributors to fatigue. For them, insufficient sleep is not a common problem. Fatigue caused problems negotiating traffic for light drivers, but problems with vehicle control and monotony for heavy drivers.

Fatigue caused by different task demands over a sustained period may also be exacerbated by several conditions that apply across the road haulage sector. These include the following, each of which may restrict sleep quantity or quality, and/or exacerbate task effects:

- Unfavourable sleeping conditions faced by many truck and bus drivers, including many nights away from home (Mackie and Miller, 1978)
- Considerable off-duty time looking for loads (Mackie and Miller, 1978)
- Need to deliver on time in order to compete or tight schedules, which forces high shares of drivers to exceed hours of work/driving regulations (Williamson et al., 1996; Williamson et al., 2003; Charlton and Baas, 2006; Braver et al., 1992).
- Incentive payments (payment by km travelled or tonnage delivered), which are associated with longer working hours, greater distances and higher fatigue for drivers (Williamson and Friswell, 2013), are of concern since high shares of drivers may be paid by incentive rather than hourly (over 70 per cent in some studies).
- Non-driving work. All drivers have non-driving work as part of their duties, but far from all are paid for it (Williamson and Friswell, 2013). Short-haul drivers may have more non-driving work (Williamson and Friswell, 2008; Friswell et al., 2006). Soccolich et al. (2013) found that in terms of safety critical events, there was a time-on-task effect across hours, but no difference between the 11th hour of driving and either 8, 9 or 10th hour. However, safety-critical events increased across all work hours when non-driving work was included in addition to driving work (Soccolich et al., 2013). Interestingly, however, naturalistic studies show that long-haul drivers who are fatigued had spent *less* time physically loading and unloading, suggesting that physical activity might contribute to increased fatigue (Hanowski et al., 2011).
- Waiting time. Drivers who wait in queues have been found to experience more frequent fatigue and more non-driving work than those who do not (Williamson and Friswell, 2013). Drivers who were not paid to wait did the longest trips, broke driving time rules, had highest fatigue and work-life conflict.

Finally, Crum and Morrow (2002) employed the measure "frequency of driving tired" among US truck drivers as a dependent variable in regression analyses, and found support for a model that fatigue depends on truck driving environment (time regularity, quality of rest and trip control) and economic pressures (scheduling demands of commerce, driver economic or personal factors, carrier economic factors). The effects on fatigue of these factors was moderated by carrier support for driving safety. An alternative regression analyses on a multinational sample showed

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driving while tired was positively related to motorway driving, dissatisfaction with schedule, and company approach (Adams-Guppy and Guppy, 2003). Other regression analyses show waiting and incentivised pay as significant predictors of fatigue (Williamson and Friswell, 2013).

Sleep quantity and quality

In the US national survey, about one in five truck, bus and taxi drivers reported getting less sleep than needed, a greater share than a control group representative of other occupations (National Sleep Foundation, 2012). 17 per cent of truck drivers and ten per cent of bus drivers slept less than six hours on workdays (National Sleep Foundation, 2012). A study by Diez et al. (2011) found that of those truck drivers who slept less than seven hours, only 36 per cent were aware of the deficit, implying that the above self-reports may underestimate the shares getting little sleep. The study also found that subjective sleep length, time in bed and total sleep time were lower for those working mornings (by one hour on average). Other studies concur that most sleepiness problems have been found for those starting shifts earliest (between 0400 h and 0500 h) (Adams-Guppy and Guppy, 2003). Sleepiness-related problems have been found across driver groups including those transporting dangerous goods or passengers (Häkkänen and Summala, 2000a). Moreover, the link between sleep restriction and accidents is convincing. For all, accidents at leisure, while commuting and at work has been found to increase in line with each hour of sleep less per night (Carter et al., 2003).

Problems related to sleepiness may be most severe for those driving through the night or working night shifts, not least due to circadian effects. Fatigue appears to be most commonly experienced by drivers between 0400 h and 0600 h (Williamson et al., 2003), in line with the trough in the circadian sleep cycle. Other studies find that drowsiness episodes are over eight times more likely to occur between 1200 h and 0600 h, which implies that risks may be heightened during late night and early morning driving generally (Wylie et al., 1996). Indeed, several authors note that accident rates for truck drivers peak somewhat earlier in the night – closer to midnight than to the circadian low between 0400 h and 0600 h (e.g. Williamson et al., 2011). Other factors than circadian drives thus appear to play a role in driver fatigue during night driving. These probably include increased homeostatic sleep pressure due to problems sleeping during the day before night drives, and time-on-task effects as drivers near the end of trips in the hours just after midnight (Baulk et al., 2009). As regards time-of-day effects for those drivers who do not drive at night, 28 per cent have said that they were most susceptible to fatigue between 1300 h and 1800 h, with a peak at 1400 h, reflecting a second circadian trough, the so-called post-lunch dip (Williamson and Friswell, 2008; Friswell et al., 2006).

In real driving, the effects of fatigue on alertness and performance are probably due to a combination of time of day and time on task. For instance, one study shows that end-of-the-drive subjective sleepiness and alpha burst activity (a physiological indicator of sleepiness) in night-time professional drivers were both significantly correlated with total work hours and arrival time, but not with age, diurnal type, prior sleep length, total break time, drive time or prior time awake (Kecklund et al., 2001). A regression analysis showed that total work hours and total break time predicted 66 per cent of the variance of alpha burst activity during the end of the drive, indicating that factors other than time of day and sleep drives also play an important role in driver fatigue.

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Activity, diet and health

Several studies find that relatively high shares of obesity in professional drivers exacerbate the problem of restricted sleep. For instance, Carter et al. (2003) found that compared to a control group, professional drivers had greater body-mass index (27 vs 26), sleep apnea (30.6 per cent versus 29.8 per cent) and more sleep debt, which may have explained elevated levels of daytime sleepiness measured using Epworth Sleepiness Scale. A recent US survey found that one in ten bus and truck drivers have been diagnosed with a sleep disorder (National Sleep Foundation, 2012). Howard et al., (2004) found that 16 per cent of Australian truck drivers in their sample had sleep apnea, and 24 per cent of drivers had excessive daytime sleepiness, the latter being related to increased accident risk. Sleep apnea has been found to be present in lower shares of long and short-haul drivers in a Finnish sample (4 and 2 per cent, respectively), equivalent to rates for the general population (Häkkänen and Summala, 2000b).

Whatever the prevalence, sleep apnea appears to be clearly linked to daytime sleepiness. A study by Asaoka et al. (2010) found general prevalence rates for sleep apnea among Japanese public transport shiftworkers of 3.7 per cent, but sleep apnea was found in 20 per cent of those with excessive daytime sleepiness. A multiple logistic regression analysis by Braeckman et al. (2011) showed that obstructive sleep apnea increased the risk of excessive daytime sleepiness by 3-fold, with significant but weaker contributions from lower educational level, smoking and an unrealistic work schedule. Physical activity has been found to be protective for the risk of sleep apnea in truck drivers, and therefore fatigue (Moreno et al., 2004). In addition to causing sleep problems, being overweight can lead to health problems which in and of themselves can be exhausting to live and work with. In Williamson et al.'s (2003) sample, 15 per cent had a body-mass index over 30, and 67 per cent had major health problems, mostly related to lower back pain, stomach problems or leg or arm problems. Apart from considerations of body-mass index and sleep apnea, poor diet may be somewhat overlooked as a fatigue-related factor among professional drivers. Drivers in one sample, for instance, were found to have eaten only one and a half nutritious meals per day (Baas et al., 2000).

Social activity or factors related to life outside work

A study by Charlton and Baas (2006) implied that hours of social interaction in the period prior to driving was one of five main activities predicting subjective fatigue ratings, along with prior hours driven prior, hours of sleep in past 48 h, whether or not the driver was on night-shift, and physical work. Off-the-job behaviour has been found to be responsible for fatigue incidents involving long and short haul trucking in the US (Hanowski et al., 2011). On the whole, however, there are few, if any, considerations of the effect of life outside work on fatigue at work in truck or bus drivers.

Demographics and individual factors

Most considerations of demographics involve driver age. Harris and Mackie (1972) pointed out general problems for older truck drivers, in terms of increased alertness decrements, larger steering wheel declines and a greater proportional increase in accidents in line with time driving, each of which may be linked to fatigue. Response of drivers to the question "How tired are you after shift?" have been found to increase significantly according to driver age (Alrukaibi and Koushki, 2008; Moe, 2006; Williamson and Friswell, 2008). On the other hand, there are claims that older drivers are better able to compensate for fatigue-related decrements, along with

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evidence that younger drivers use less off-duty time sleeping (Mackie and Miller, 1978).

In addition to age, demographics usually include measures of age, marital status, and number of and age of children, but these are rarely reported (Williamson et al., 2003). Either these factors have little effect or they may be overlooked by researchers for some reason.

Several factors together

A factors analysis by McCartt et al. (2000) reduced a large set of predictors of sleep at wheel in professional drivers down to eight key predictors: daytime sleepiness; demanding schedules; more hours of work; fewer hours off duty; older drivers; shorter sleep on road; sleep disorders; and a greater tendency to night-time drowsy driving. The study by Häkkänen and Summala (2000a) suggested that sleepiness is strongly related to prolonged driving, sleep deficit, and drivers health status, with the effects of latter two factors being interactive and cumulative. In studies by Williamson's group the drivers themselves reported long driving hours, loading operations, insufficient sleep during and before trips, poor roads, monotonous roads and dawn driving as the greatest contributors to fatigue (Feyer and Williamson, 1995b; Williamson et al., 1992). Thus several studies conclude that organization and length of work and driving tasks (including task type, breaks and time of day), along with restricted sleep and poor driver health are main factors influencing fatigue and sleepiness in professional drivers on the road.

Outcomes

Mackie and Miller (1978) suggested that deterioration in driver status was in line with an increase in accident rate after 6.5 h of driving, but subsequent studies do not seem to concur (Williamson et al., 2011). Thus, while many studies agree that increasing fatigue is experienced as real driving tasks progress, and that this has physiological correlates as well as possible latent performance effects, there is less certainty about the effects on safe driving performance.

Falling asleep at the wheel is perhaps the most relevant outcome of fatigue for those interested in improving transport safety. A self-report measure of how often drivers have fallen asleep in the preceding 12 months is most often used, but again time periods vary, and sometime they are not defined at all (Sabbagh-Ehrlich et al., 2005). The share of professional drivers who say they have fallen asleep in the preceding 12 months varies from under ten per cent to almost 50 per cent (Phillips and Sagberg, 2013; McCartt et al., 2000; Williamson and Friswell, 2008; Friswell et al., 2006). This variation is probably due not only to the presence of different profiles of those fatigue contributors we consider above, but to the varying driving distances involved in different countries. Different road standards may also contribute, with motorway driving having been found to be an independent contributor to driving while tired (Adams-Guppy and Guppy, 2003).

Reductions in cognitive performance are indicative of the effects of fatigue that may go beyond sleepiness. 24 per cent of a sample of New Zealand drivers failed pre-defined psychomotor performance criteria (Charlton and Baas, 2006), and reaction time was shown to increase with time spent driving (Diez et al., 2011). 72 per cent of drivers in a Dutch study said that fatigue adversely affects their driving, reporting reduced attention, slower reactions and poorer steering as symptoms (Sluiter et al., 1999). Poorer steering and slowed reactions were also reported as common fatigue

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effects in another study, along with poor gear changes and driving too slowly (Williamson et al., 2003).

However, the ultimate measure of interest for those involved in traffic safety is fatigue-related near misses or accidents. Due to the low numbers involved and difficulties of assigning fatigue as a cause, a proximal measure is often used in the form of self-reports on fatigue-related near misses. Significant correlations have been found between reports of driving tired often and near misses (Adams-Guppy and Guppy, 2003). 21 per cent of drivers in an Australian study reported at least one fatigue-related incident (although a time period was not defined), the most common of which were classified as crossing lane lines (11 per cent), nodding off (5 per cent), having a near miss (5 per cent) or over- or understeering (Williamson et al., 2003). 13 per cent of drivers in Sabbagh-Ehrlich et al.'s (2005) study reported that they had been involved in a sleep-related crash. In naturalistic studies of long and short-haul trucking, independent observations showed that eye-closure rates preceding critical incidents for which the driver was at fault were significantly greater than those preceding critical incidents for which they were not at-fault (Hanowski et al., 2011). Analysis showed that drivers assessed to have been fatigued prior to an at-fault critical incident reported less sleep (5.3 h) than those assessed not to have been fatigued (6.13 h). The findings are consistent with the idea that poor sleep results in sleepy driving and a greater risk of a critical incident.

The health effects of fatigue have been studied to a limited extent. Postural stability decrements after a night of work have been found (Albuquerque et al., 2011). Regression analysis supports that the need for recovery after work is a major predictor of psychosomatic complaints, sleep complaints and complaints of emotional exhaustion in bus drivers (Sluiter et al., 1999). According to Milosevic's (1997) questionnaire study, frequent fatigue signs for professional drivers include pains in legs, back pain, drowsiness, bad mood, irritability and eye pain. Back pain was dominant towards the end of the shift, as has been reported by others.

4.1.6 Summary

Data have been collected for operators of road transport using a variety of methods and many different measures of fatigue. A wide range of fatigue causes and outcomes have been considered. Most studies are based on cross-sectional questionnaire or diary data. Several studies combine data collection methods, and a notable number collect objective measures of sleep quantity and quality alongside the surveys. There is limited use of objective measures of fatigue, either using physiological measures of drivers and naturalistic observations. Examples of other types of fatigue study include measurements of fatigue before and after a driving session (Milosevic, 1997), controlled experiments on the effect of truck type on truck driver fatigue (Battelle Human Factors, 1996), and experiments comparing the effect of shift types on fatigue responses (Diez et al., 2011).

Survey studies can attempt to link health and health behaviour to fatigue risks (Moreno et al., 2004), or examine the effect of recent sleep deprivation (Albuquerque et al., 2011) or driving exposure (Milosevic, 1997) on acute fatigue. However, most attempt to capture the relative or combined effects of a range of factors on fatigue and safety-related performance (Carter et al., 2003; Charlton and Baas, 2006; Häkkänen and Summala, 2000a; Mackie and Miller, 1978; Adams-Guppy and Guppy, 2003; Sabbagh-Ehrlich et al., 2005; Williamson et al., 1996; Baas et al., 2000; Feyer

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and Williamson, 1995; Häkkänen and Summala, 2000b; McCartt et al., 2000; Williamson et al., 1992; Williamson and Friswell, 2013).

4.2 Rail

There would appear to be fewer studies on fatigue in locomotive engineers than on drivers working in road transport. This may be due partly to better working conditions, partly because there are fewer of them, and partly because there are safety barriers in place to prevent catastrophe should the driver fall asleep. These barriers include a "deadman's pedal", which activates the brake when it is released by the sleeping driver, and automatic braking systems, which are activated when the driver ignores audible and visual warnings that they should be taking appropriate action (Phillips and Sagberg, 2014). Despite such barriers, operator fatigue is still a serious threat to safe rail transport. Automatic braking systems are not always present and do not always work. Fatigue also presents other dangers than those related to sleepiness, such as poorer decision-making or increased risk of employing an incorrect mental model for developing situations (Phillips and Sagberg, 2014). Given that drivers often have the power to override automatic systems, the mentally exhausted driver may be as much of risk as a sleepy driver to safe rail transport.

Rail transport involves either cargo or passenger transport. Cargo transport occurs more often at night. It involves more shunting operations in station areas, which though they occur at relatively low speed, often occur without automated braking systems and involve crossing other tracks. Shifts in cargo transport are less predictable (Gertler and DiFiore, 2010). Cargo trains also tend to travel longer distances with fewer stops. Passenger transport by train, especially local transport, is characterized by more time pressure due to more frequently scheduled stops. In both forms of rail transport, the locomotive engineer will be subject to extreme routine, periods of high demands, and a driving task characterized by vigilance. More information on the nature of the job of the locomotive engineer is given in Phillips (2014a) and in a series of symposia on rail human factors (Wilson, Mills, Clarke, Rajan, and Dadashi, 2012).

4.2.1 Contributors and outcomes studied

Contributing factors studied span five main groups:

- Sleep and schedules. Sleep variables commonly studied are usually collected using standard self-report measures and include: sleep length; sleep habits; sleep problems; sleep sufficiency; napping; and ability to go to or stay sleep; and sleep conditions (Ingre et al., 2004; National Sleep Foundation, 2012; Härmä et al., 2002; Paterson et al., 2012; Barton et al., 1995; Robertson et al., 2010; Dorrian et al., 2011; Pilcher et al., 2005; Cabon et al., 2012). Sleep quantity and quality are also collected objectively by several studies using actigraphs (Asaoka et al., 2010; Paterson et al., 2012; Dorrian et al., 2011; de Araújo Fernandes et al., 2013). There is particular emphasis on the effect of schedules on sleep, where schedule variables studied are: length of average shift; schedule regularity; predictability and rotation patterns; number of times schedule starts at night; average length of time between shifts; and working hours (National Sleep Foundation, 2012; Paterson et al., 2012; Härmä et al., 2002; Gertler and DiFiore, 2010; Barton et al., 1995; Asaoka et al., 2010; Cabon et al., 2012; Robertson et al., 2010;

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McGuffog et al., 2004). It is important to consider whether studies collect data on actual schedules worked or on planned schedules, as the two may differ substantially (Cabon et al., 2012). Variables describing actual schedule history have been used as the basis of fatigue risk calculations (Raslear et al., 2013; Dorrian et al., 2007).

- Occupational factors and framework conditions. Organisational factors studied include organisational support, autonomy, job control and support, interpersonal relationships, interpersonal conflict, job satisfaction, working environment (Barton et al. 1995; Tucker and Rutherford, 2005), training courses and length of service (Gertler and DiFiore, 2010; Härmä et al., 2002). Time in limbo at work (Robertson et al., 2010), break time (Gertler and DiFiore, 2010), perceived workload and job-related stress have also been studied (Ingre et al., 2008; Åhsberg, 2000; Dorrian et al., 2011). Overtime worked or shifts swapped (Robertson et al., 2010) and how much driving is done during a shift (Robertson et al., 2010) have also been considered.
- Health/dietary habits, physical activity, health status and sleep disorders. Specific variables studied include general health status, physical and psychological symptoms (Gouin et al., 2001; Gertler and DiFiore, 2010; Ingre et al., 2008; Asaoka et al., 2010), alcohol and medicine use (Härmä et al., 2002), caffeine use (National Sleep Foundation, 2012; Paterson et al., 2012; Gertler and DiFiore, 2010; Ingre et al., 2004), body-mass index (Paterson et al., 2012; Härmä et al., 2002; Asaoka et al., 2010) and sleep apnea (Asaoka et al., 2010; Hack, 2005).
- Social activity or factors related to life outside work that have been studied include commuting time (Gertler and DiFiore, 2010; Robertson et al., 2010; National Sleep Foundation, 2012; Paterson et al., 2012) and social support from friends and family (Tucker and Rutherford, 2005).
- Demographics studied include domestic status, partner's employment status (Paterson et al., 2012), dependents (Härmä et al., 2002) and circadian type (de Araújo Fernandes Jr et al., 2013)

As for the road studies, most studies include two or more of the four main types of contributing factors listed above, and factors most often studied are again those in the first two groups. While several studies are concerned with health, some focus more on the effect of fatigue or restricted sleep on operator health, rather than the effect of health on fatigue. As in the road sector, social activity or factors outside work have tended to be under-emphasized in relation to sleep- and task-related factors, although a few of the studies here do consider commuting time.

Outcomes considered concern mainly health and performance. Relevant health measures used as dependent variables include the Sheehan disability scale to determine sleep impact on mood, family/home, social life and work (National Sleep Foundation, 2012); sickness absence (Härmä et al., 2002; Gertler et al., 2013); and general health status and wellbeing (Gertler et al., 2013; Gertler and DiFiore, 2009; Ku and Smith, 2010; Tucker and Rutherford, 2005). Shiftwork disorder and its associated sleep and health aspects have also been measured as a possible outcome of chronic fatigue (Asaoka et al., 2010). An important mediator of the effects of tiring work and schedules on health may be the need for recovery from work (Robertson et al., 2010). Studies on the effect of fatigue on performance often consider cognitive performance measured using a psychomotor vigilance test before and after a nightshift (Jay et al., 2005; de Araújo Fernandes Jr et al., 2013; Härmä et al., 2002). Robertson et al. (2010) studied performance by asking drivers to report on the frequency of mistakes they made while on shift, and reports of near misses at work

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due to sleepiness have also been used (National Sleep Foundation, 2012). The effect of fatigue on driver eye movements in relation to track environment has been assessed by naturalistic studies (Gouin et al., 2001). Dorrian et al. (2007) exploit the fact that the railway operator intermittently downloads data for trains to monitor handling for quality control and training purposes, enabling them to measure driver performance, in terms of fuel use, fuel consumption, braking and speed, for drivers on shifts with varying risks for fatigue.

4.2.2 Populations studied

Most studies sample a local population of train operators who are not representative of the population of train operators for a certain country. Drivers tend to be sampled from a single train company, a single depot, may work a defined and sometimes unusual shift pattern, or may be studied because they only work long or short distances. Most studies included here are based on at least 100 drivers, although more resource intensive studies, such as those involving naturalistic observations or EEG measurements, tend to involve less. Railway conductors are involved in several studies (e.g. National Sleep Foundation, 2012; Gertler and DiFiore, 2009, 2010; Raslear et al., 2013; Ku and Smith, 2010; Dorrian et al., 2011), and there is also some consideration of traffic controllers (Härmä et al., 2002; Raslear et al., 2013; Dorrian et al., 2011). A report by Gertler et al. (2013) summarises extensive research on fatigue among various roles in the US railroad.

4.2.3 Data collection and methods

In-depth cross-sectional multi-method studies on relatively few drivers are popular. These typically combine surveys with sleep logs or work diaries, actigraphs and/or cognitive performance tests (Härmä et al., 2002; Paterson et al., 2012; Ingre et al., 2008; Asaoka et al., 2010; Cabon et al., 2012; Robertson et al., 2010; Dorrian et al., 2011; McGuffog et al., 2004; Jay et al., 2005). Rather than surveys of sleep and work patterns over a historical period, many of the rail studies carry out survey measurements in real time, or combine such measurements with survey data on sleeps or schedules immediately preceding the survey time (e.g. Ingre et al., 2004). Schedule analysis software has also been employed in order to output fatigue predictions and investigate the importance of schedules on actual fatigue levels (Gertler and DiFiore, 2010), or in order to examine whether schedule type affects actual driving performance (Dorrian, Hussey, and Dawson, 2007). As we have noted, there appears to be particular emphasis on the effect of schedules or the driving task on aspects of health and wellbeing in addition to fatigue (Gertler and DiFiore 2010; Gouin et al., 2001; Hack, 2005).

A range of recruitment techniques and study designs are used, as represented by the following studies:

- Paterson et al. (2012) invited driver participation through recruitment sessions and posters at companies. Participants were then sent a pack in the post with a survey, sleep and work diaries, and an actigraph. They were asked to fill in diaries and wear the actigraph over a two-week period.
- Härmä et al. (2002) issued questionnaires and sleep diaries to participants on a first visit to a sleep laboratory, and asked them to return after 21 days. In the intervening period, diaries, which included measures of momentary sleepiness, were completed every day. Cognitive performance tests were carried out the day after the study period.

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- Gertler and DiFiore (2010) asked drivers to complete a background mail-survey and fill in a daily log for 2 weeks.
- Ingre et al. (2004) asked 17 experienced drivers to drive a 4.5 h trip in two directions, with 2.5 h break in between, on either an early shift (ca. 0600), day shift or evening shift. Drivers were asked to report retrospective ratings of momentary sleepiness (measured using Karolinska Sleepiness Scale) at each stop, and a sleep diary was filled out on the morning before each drive.
- Cabon et al. (2012) combined a large-scale survey with a smaller scale field study involving actigraphy and a sleep log covering days at work and days off before and after a working period. Fatigue was also assessed during trips by EEG and EOG, momentary sleepiness ratings. The Sleep Wake Predictor model was used to predict sleepiness from schedules worked, and compared with actual values.
- Web panel data was collected by a market research company in the US national study of sleep (National Sleep Foundation, 2012).

Although not always reported, general response rates can be quite low (in one study less than ten per cent), although this varies from recruitment technique and from country to country.

4.2.4 Operationalization of the fatigue state

Reflecting an interest in acute fatigue, momentary measures of fatigue are most often used. The Samn-Perelli fatigue scale (1= fully alert, wide awake, 7= completely exhausted unable to function) can be considered to capture broader fatigue, i.e. not just sleepiness (Samn and Perelli, 1982). It appears to be a favoured by researchers in English-speaking countries, and is suitable for diary use, where drivers can report their fatigue levels before, after and/or during a shift (Paech, Ferguson, Sargent, and Roach, 2011; Paterson et al., 2012; Robertson et al., 2010; McGuffog et al., 2004; Dorrian et al., 2011; Jay et al., 2005). A similar but different scale is employed by Gouin et al. (2001), while a visual analog scale for momentary fatigue was employed by de Araújo Fernandes Jr. et al. (2013). Momentary sleepiness is also recorded at various times in relation to a shift by several studies, using the Karolinska Sleepiness Scale (Härmä et al., 2002; Ingre et al., 2004; Hack, 2005), with one study comparing actual sleepiness with sleepiness predicted by schedule software analysis (Cabon, Deharvengt et al. 2012). The latter also attempted to measure sleepiness objectively using EEG and EOG. Pilcher et al. (2005) operationalize fatigue in terms of restedness on waking, while emotional aspects of fatigue are emphasized by Ku and Smith (2010), who employ scales selected from the POMS mood status checklist. Others operationalize momentary fatigue by measuring the level of alertness or dimensional fatigue at the start and/or end of each work period (Gertler and DiFiore, 2009; Pilcher et al., 2002; Åhsberg, 2000). Excessive daytime sleepiness is also measured, but appears to be less favoured by rail than road studies (National Sleep Foundation, 2012; Asaoka et al., 2010). Chronic fatigue does not appear to have been accounted for in any depth, but has been measured, for example using the Standard Shiftwork Index (Tucker and Rutherford, 2005).

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4.2.5 Findings

Prevalence

Hack et al. (2007) reports that the wake-time sleepiness of train operators was in the normal range (Epworth Sleepiness Scale=6.98), but that 23 per cent rated it as above normal (Epworth Sleepiness Scale=9). However, no differences were found on scores of excessive daytime sleepiness for a sample of US train operators compared with other occupational samples (National Sleep Foundation, 2012). Otherwise, a focus on momentary measures of fatigue during a shift in response to schedules worked makes it hard to extract general prevalence rates from the field studies included here. Another problem is that it is difficult to know to what extent the samples used represent the national population of train operators. Nevertheless, it may useful to compare momentary sleepiness rates for different driver samples. For instance, using a Karolinska Sleepiness Scale score of 7 or more as a measure of severe sleepiness, Härmä et al. (2002) found that half of drivers and controllers working night shifts in their sample became severely sleepy during their shifts, compared with 20 and 15 per cent of those working morning and afternoon shifts, respectively. However, Ingre et al. (2004) found that 82 per cent of drivers reported a bout of severe sleepiness (Karolinska Sleepiness Scale 7 or more) during their early shift, at least once during drive. Using the Samn-Perelli measure of momentary fatigue, Dorrian et al. (2011) found a mean rating per shift of 4.0, indicating that the drivers were "a little tired, less than fresh". 13 per cent were highly fatigued, rating Samn-Perelli as 6 or 7 (Dorrian et al., 2011). As one would expect, momentary sleepiness and fatigue rates vary widely with time of day, such that it is difficult to conclude anything about prevalence for different samples unless they are measured under the same conditions, which is rarely the case. One way in which this could be done is to measure fatigue following a shift conducted at a certain time of day.

The Swedish Occupational Fatigue Index (SOFI) assesses fatigue after work, along dimensions of lack of energy, physical exertion, physical discomfort, lack of motivation and sleepiness (Åhsberg, 2000). Train operators were found to score higher on the sleepiness subscale of SOFI than either bus drivers, teachers, cashiers or firemen (Åhsberg, 2000). They also scored joint highest on a subscale for lack of motivation, along with bus drivers. Scale scores indicated that the train operators experienced relatively low physical demands, but that lack of control is high (second highest to bus drivers in Åhsberg's (2000) study). A study of workload ratings, measured using the NASA-TLX, confirms that mental rather than physical demands can be high (Dorrian et al., 2011). Thus regarding prevalence, it may be important to attend to different dimensions of fatigue.

Contributors

Sleep

The US national sleep survey suggests that 34 per cent of train operators get less sleep than needed, a share only exceeded by air pilots (National Sleep Foundation, 2012). Sixteen per cent of train operators sleep less than 6 h on working days, and 44 per cent of train operators said schedule did not allow adequate sleep, more than any other group. An analysis of rail employees in Australia by Dorrian et al. (2011) showed that 13 per cent working shifts had slept less than 5 h in the prior 24 h (average 7.6 h), and 25 per cent had slept less than 12 h in prior 48 h (average 15 h). Sixteen per cent had been awake for 16 h or more. (Dorrian et al., 2011) In

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contrast, authors of the US studies emphasise that rail personnel may get more sleep than normal workers, but it is the *quality* and *cause* of this extra sleep that is important (Gertler and DiFiore, 2009). For instance, Pilcher et al. (2005)'s study of on-call cargo crews finds that due to napping the crews get more total sleep than crews on more regular schedules, but shorter main sleep lengths, and that this leads to problems going to sleep, staying asleep, and feeling poorly rested on waking.

Several studies find that sleep lengths may be determined by subsequent shift start times. For instance Ingre et al. (2004) reported that sleep length was longest for their sample before day and evening shifts, and shortest before early morning shift. Ratings of insufficient sleep were found to be more pronounced before the early morning shift. McGuffog et al. (2004) reported that sleep length was reduced from over 7 h for late morning shift starts, to 4.8 h for shifts starting between 0400 h and 0430 h. Most train operators working early shifts in a mine were also found to have the least sleep (less than 6 h) (Paech et al., 2011). Cabon et al. (2012) also found that sleep deficit was highest before morning duties, but also after night duties, when operators had attempted to sleep in the day. Ingre et al. (2008) reported sleep lengths under 6 h for subsequent shift start times between 0300 h and 0600 h, which increased linearly up to 8 h for shifts starting after 0900 h. Paterson et al. (2012) report that night shifts afford the least sleep, followed by afternoon shifts, and then (later) morning shifts.

Schedules

Several studies provide evidence that train operators work challenging schedules that may place high pressure on sleep, and thus explain why there is a research focus on schedule effects on sleepiness. According to the US national sleep survey (National Sleep Foundation, 2012):

- Train operator average shift lengths were 9.8 h, significantly longer than a control group representing other occupations (8.5 h).
- Almost 10 per cent of train operators work average shifts longer than 12 h (cf. 3 per cent of the control group).
- Less than 50 per cent of train operators work same schedule each day, compared with 76 per cent of the control group
- When they do work a routine schedule, it is less likely to start between 0600 h and 0900 h.
- Train operators started a shift between 2200 and 0330 h on average 2.7 times in the last 2 weeks.
- Train operators spent more hours working per week (52 h on average) than bus/taxi (38 h a week) or the control group (43 h a week).

UK studies support that train operators often work long hours (Robertson et al., 2010; McGuffog et al., 2004):

- 1 in 5 reporting working over 13 h at least 3 times a year.
- 6 per cent work over 50 h a week.
- They work an average of 5 hours of overtime a week.
- Their average shift length is between 8.5 and 9 hours.

Most drivers in these studies worked all types of shift start and end times. Drivers typically worked four to five consecutive shifts of the same type before rotating. The UK studies also found that relatively high shares of train operators work nights, that the operators find it hard to sleep after nightshift (6 h average sleep length) or before a day shift (7.3 h) (Robertson et al., 2010). They also suggest an increase in fatigue

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with consecutive duties without a rest day, and inadequate recovery time between a night or early shift and a following day shift (Robertson et al., 2010). These effects may be exacerbated by reports of frequent changes to roster at short notice (Robertson et al., 2010).

Australian studies found that 7 per cent of rail employees in a sample worked shift lengths of 10 h or more, with nearly 40 per cent of driver shifts breaching working hours or driving time regulations (Dorrian et al., 2011). Paech et al. (2011) exploited a shift system in which train operators worked 12-hour shifts that started at all hours during the day, in order to study shift start times. Shift start time had a main effect on fatigue levels at both start and end of the shift, with higher fatigue at the start of shifts between 2000 h and 0400 h than for those starting between 1000 h and 1600 h. This agrees somewhat with diary studies showing highest levels of fatigue at the start of early shifts (McGuffog et al., 2004). Interestingly, shifts starting between 0400 h and 1000 h were associated with lower fatigue at the end of shift. Fatigue was reported generally to increase across shifts on all shifts except for those starting between 2200 h and 0400 h, in which case it was the same. Härmä et al. (2002) report data indicating that the risk of severe momentary sleepiness (Karolinska Sleepiness Scale above 7) increases with shift length by as much as 15 per cent for each hour of the shift, and that the risk of severe sleepiness is not related to time-off before shifts.

A large US study has mapped differences for passenger train operators working split versus continuous shifts (Gertler and DiFiore, 2010). Those working split shifts worked less hours in total (average 39 h a week) than those who work continuous shifts (average 45 h a week), although it was not clear whether the long time-span of work may ultimately be more disruptive to the main sleep. Those working split shifts tended to nap between shifts, which may partly explain why self-rated alertness declined from start to end of work for all but split-shift group. Personnel in both groups had to make full use of breaks and time between shifts to get adequate sleep/rest. The same US study program also charted schedule-related challenges for operators of cargo trains (Gertler and DiFiore, 2009). The main difference for this group was whether they worked variable or fixed schedules. The main sleep length was found to be similar for all groups, but those on variable schedules had worse sleep quality, slept away from home more, and often had to manage fatigue by resting or napping between noon and 2 am. A lower share of those on a variable schedule than those on a fixed schedule reported that they were frequently or always alert at work (43 per cent versus 60 per cent, respectively) (Gertler and DiFiore, 2009). Those on variable schedules also had higher sickness rates, which the authors suggested might be due to a greater need to recover from fatigue. The study also found that those who worked shifts over nine hours in duration tended to give worse alertness ratings. In a summary of the US studies, Raslear et al. (2013) state that work schedules largely determine sleep patterns in train operators, which in turn determine fatigue exposure. Comparing cargo and passenger operators, they found that the latter were less exposed to fatigue, primarily due to greater schedule predictability. Operators of passenger trains in the UK also appear to work slightly less challenging schedules that goods train operators (McGuffog et al., 2004).

Other occupational, organisational and sectoral conditions

According to levels of reported momentary sleepiness, trips themselves can be fatiguing, with a clear shift in the distribution of sleepiness scores as trips progress (Cabon et al., 2012). Clearly, the time of day of the shift must be considered, but generally drivers themselves concur that fatigue builds as trips progress (Robertson et

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al., 2010). An increase in fatigue across a shift may not only depend on time of day but the length of continuous driving periods and the timing and length of breaks (McGuffog et al., 2004). In one UK study 16 per cent of drivers said they worked longer than 6 h without a break, because they had to take their break early or late in the shift (Robertson et al., 2010). Ingre et al. (2004) found distinct peaks in sleepiness for some segments of early shift, across drivers. Analysis showed this not to be due to time of day variations, but length of drive between stops. Thus a combination of early time and monotonous task may be dangerous in terms of fatigue development.

One study suggests that the rail sector may have oversimplified the effects of scheduling by the organization on driver fatigue (Ku and Smith, 2010). Other organisational factors, such as job demands and control are also found to correlate with working hours, for instance. Moreover, social wellbeing was found to be an important mediator between a range of organisational effects and fatigue, i.e. there were no direct effects between scheduling and fatigue. The authors conclude that the organization may affect fatigue by influencing social wellbeing outside work in a number of ways, only one of which is scheduling.

Finally, a popular organisational measure for those concerned with fatigue is training. However, substantial shares of drivers report not receiving training, and when there is training it can be of little use (Robertson et al., 2010).

Activity, diet and health

In the US, 14 per cent of train operators have been diagnosed with a sleep disorder (National Sleep Foundation, 2012). Body-mass index is often higher for locomotive engineers than for population norms (Dorrian et al., 2011; Hack et al., 2007). In a UK sample, 28 per cent were reported as obese, i.e. with a body-mass index of 30 or more, which was associated with elevated sleep problems (Robertson et al., 2010). Seven per cent of another UK sample of operators were found to have sleep apnea using strict criteria, compared with three per cent prevalence in the general population (Hack et al., 2007). Short notice changes to the roster were also found to be correlated with stress, insomnia and other health issues. Accounting for a broad range of factors, the Robertson et al. (2010) study found that a lack of roster stability, with frequent changes at short notice, and lack of control over working hours and shifts worked were correlated with aspects of sleep, fatigue, health and wellbeing (Robertson et al., 2010).

Demographics and factors related to life outside work

One study reports that having dependents is a main limiter of sleep quantity for train operators, but that it is not associated with subjective fatigue (Paterson et al., 2012). De Araújo Fernandes Jr. et al. (2013) find 41per cent train operators morning types, 7 per cent evening types and the rest intermediate types. Evening types had a tendency to remain awake longer before night shift, and there was an indication that they scored worse on quality of life than did morning types.

Outcomes

Given a high exposure to fatigue from irregular and unpredictable schedules, various fatigue-related outcomes might be expected. The US survey finds that poor sleep has relatively high effects for locomotive engineers, on mood (13 per cent vs. 5-9 per cent other groups), dissatisfaction with family life (11 per cent vs. 4-5 per cent others) and poor social relations (National Sleep Foundation, 2012). More alarmingly, 39 per cent of train operators reported that they drove while drowsy when not at

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work at least once a month, compared with 22 per cent of truck drivers and 24 per cent of a group representing other occupations. Operators also reported more than others that they were affected by fatigue while at work, with 26 per cent of train operators saying sleepiness affects their job at least once a week, compared with 15 per cent truck drivers and 17 per cent of the control group (National Sleep Foundation, 2012). Summarising the US field study program, Raslear et al. (2013) provides data suggesting that fatigue exposure was exponentially higher for crews and dispatchers involved in accidents than it was for those not involved in accidents. Others report a strong link between fatigue and health complaints for train operators (Ku and Smith, 2010).

Dorrian et al. (2007) analysed schedules in order to predict their associated fatigue levels using a "FAID-model", which assumes that fatigue levels and recovery from fatigue depends on duration, circadian timing and recency of work and rest periods[2]. They then observed that operators on schedules with higher levels of associated fatigue, had higher fuel use, heavier brake use and more frequent speed violations. Heavy braking and speeding occurred more on flat sections of the route, indicating that fatigue may affect performance more on monotonous stretches. There are claims that such operational fatigue outcomes may be more authentic and sensitive indicators of fatigue than artificial psychomotor and cognitive tests (S.M. Jay et al., 2005). Indeed, this may explain why psychomotor vigilance tests have failed to reveal differences, either between different groups of operators or schedule types or within the same operators before and after their shift (de Araújo Fernandes Jr et al., 2013).

Drivers in some samples report that mistakes may be most likely to be made in night duties and early shifts (Robertson et al., 2010). However, according to one study less than 10 per cent of operators reported that mistakes were most likely when working nights, while over 80 per cent reported most likely on early shifts (McGuffog et al., 2004).

4.2.6 Summary

Rail studies are more concerned than road studies with assessing acute sleepiness due to recent schedules worked. There is also a greater focus on the longer-term effects of fatigue, and health-related factors arising because of shiftwork appears to be a particular concern. Despite this, chronic fatigue or burnout are rarely considered explicitly. When acute or momentary fatigue is measured, there appears to be a greater tendency to consider the broader aspects of fatigue than just sleepiness. According to a dimensional measure of momentary fatigue, locomotive engineers score relatively high on sleepiness and lacking motivation when compared with other occupations. A focus on momentary fatigue or sleepiness makes it hard to conclude much about prevalence rates. The limited studies that have used a measure of daytime sleepiness (Epworth Sleepiness Scale) give mixed results as to whether it is elevated for locomotive engineers compared with other occupations.

Several studies sample a local population of train operators, and we often cannot be sure as to whether they represent the national population of train operators. A comprehensive study of in the US is an exception to this (Gertler et al., 2013). In-depth cross-sectional multi-method studies are popular. These typically combine

[2] The model has been validated using data from studies of cumulative partial sleep deprivation and continuous acute sleep deprivation. FAID predictions correlate well with PVT, subjective performance ratings, sleepiness and tiredness (Fletcher and Dawson, 2001).

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surveys with sleep logs or work diaries, actigraphs and/or cognitive performance tests. A range of recruitment techniques and study designs are evident.

Most studies suggest that sleep is a particular challenge for locomotive engineers, i.e. that they get less sleep compared with other samples, or that the sleep they do get is of poor quality. Shift start times have important effects on the length of preceding sleep bouts, with night and early shifts being most demanding. Evidence from the US and UK suggests train operators can work long, irregular hours, at all times of the day and night. Schedule-related challenges may be greater for cargo train operators. Importantly, one study claims that the direct effects of schedules on fatigue may be overestimated, and that social wellbeing may be an important mediator between a range of organizational effects and fatigue. However, it is not clear yet whether this finding is reproducible, or whether it remains true for the many different aspects of fatigue and the many different ways of measuring it.

Fatigue across a shift appears to vary depending on the time of day of the shift, but there is a general trend of increasing fatigue as the shift progresses. Long periods of driving without a rest break, and long periods of driving along monotonous track stretches will also increase fatigue or sleepiness within a shift. The effects of restricted sleep and fatigue appear to manifest in terms of health and performance. Locomotive engineers have been found to have elevated body-mass index and sleep disorder levels, poorer moods, and experience greater challenges in life outside work. The latent effects of fatigue are manifest in one finding that the share of locomotive engineers who drive while drowsy outside of work is almost double than it is for truck drivers. Finally, studies using operational performance measures, such as braking abruptness or acceleration, may be more revealing than artificial cognitive tests. One study employing these measures reveals that fatigue presents challenges for economic and safe train operation.

4.3 Sea

In many sea vessels there is a demand for continuous operation requiring round-the-clock presence of different occupational roles, especially those working on the bridge, engine room or in a safety capacity. Continuous coverage is achieved using one of a number of different shift systems. A typical shift system is “6/6” or “6-on/6-off”, where two watch groups rotate continuously between working for 6 hours and then resting for 6 hours. One watch (group) might work between 0600 h and 1200 h and between 1800 h and midnight, while the other works between 1200 h and 1800 h and between midnight and 0600 h. This is an example of a two-watch system. A “4/8” system (4 hours on/8 hours off) is an example of a three-watch system, since three watches are required to ensure round-the-clock coverage.

Safety-critical personnel keep watch on the bridge and over the running of machinery. The generic bridge personnel are a lookout and an officer or mate who is responsible for the safe navigation of the ship in terms of grounding and collision avoidance. An engineering specialist ensures that running machinery continues to operate within tolerances, and depending on the vessel they may also be present on the bridge. Most watchstanders have secondary safety-critical functions, such as maintenance or responding to any emergencies that may arise, such as fires on board and so on. According to Starren et al. (2008), maintenance is the most common secondary task in short sea (coastal) shipping. Depending on the vessel, there may

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also be secondary administrative or physical tasks. It is not unusual for watchstanders to work beyond their allocated watch hours. A study by the Accident Investigation Board Finland (2004) shows that other work preceding a watch can be substantial for bridge crew, and can last between 2 and 5 h. This may be especially true around docking times. A study involving interviews and focus groups with participants from various shipping companies, management companies and maritime colleges in the UK, Philippines and Singapore illustrated the following underlying issues associated with seafarers' fatigue (Ellis, 2005):

- long working hours,
- burden from (International Ship and Port Security) drills,
- burden of paperwork,
- falsification of documentation about working hours, and
- safety concerns due to reduction in crew sizes.

Due to the current economic climate, ships' crews are under increasing pressure from competitive voyage schedules, and there are rising concerns over incidents and accidents, which investigators and authorities attribute increasingly to fatigue. Some comprehensive fatigue studies have been funded, many concerned with the effects of different types of continuous on/off working on fatigue and fatigue-related outcomes. These include the Cardiff Sea Study (Smith et al., 2006) and Project Horizon (Barnett et al., 2012). Given the centrality of bridge crew, they are often in focus of comprehensive study.

4.3.1 Contributors and outcomes studied

Fatigue contributors studied can again be split into five main groups:

- Sleep and schedules. Sleep variables studied as possible influences on fatigue include consistency of sleep (Louie and Doolen, 2007); sleep quantity and quality (Arendt et al., 2006; Sanquist et al., 1997; Sanquist et al., 1996; Smith et al., 2003; Smith et al., 2006; Smith, Lane, and Bloor, 2001; Lützhöft et al., 2007; Accident Investigation Board Finland, 2004; Hansen and Holmen, 2011); sleep location (Ferguson et al., 2008); coping with sleep (Smith et al., 2006); and napping (Accident Investigation Board Finland, 2004; Kongsvik and Størkersen, 2011). Sleep opportunities and timings described by the watch system have also been investigated as a contributor to fatigue (Hansen and Holmen, 2011; Accident Investigation Board Finland, 2004; Kongsvik and Størkersen, 2011; Lützhöft et al., 2007; Härmä et al., 2008). Some studies notably account for actual, rather than scheduled, work start and end times, working hours per week and variable working hours (Smith et al., 2006).
- Other occupational factors and framework conditions. Factors studied in this group include port frequency/turnaround; tour length; knowledge of fatigue; job support / control / security / satisfaction; perception of risk to personal safety; multitasking on watch; and work off-watch (Parker et al., 1998; Smith et al., 2006; Smith et al., 2001). Studies also consider mental and physical job demands – especially workload (Miller et al., 2003; Bridger et al., 2010; Grech et al., 2009; Pollard et al., 1990); working environment on- and/or off-watch, including vessel motion, sea conditions and noise (Miller et al., 2003; Smith et al., 2003; Accident Investigation Board Finland, 2004; Sanquist et al., 1997; Sanquist et al., 1996); time-use and related effort (Pollard et al., 1990; Starren et al., 2008); fatigue prevalence on the vessel (Louie and Doolen, 2007); and stress related to increasing levels of automation. General application of regulations on

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board, and work safety management procedures and reporting systems have also been considered as contributors to fatigue (Kongsvik and Størkersen, 2011; Louie and Doolen, 2007).

- Health status, dietary habits, physical activity and sleep disorders are considered by several studies (Sanquist et al., 1997; Sanquist et al., 1996; Parker et al., 1998; Smith et al., 2006; Accident Investigation Board Finland, 2004; Kongsvik and Størkersen, 2011; Bridger et al., 2010), and there are considerations of body-mass index, apnea (Accident Investigation Board Finland, 2004; Parker et al., 1998), medicine use (Accident Investigation Board Finland, 2004), and sea sickness (Parker et al., 1998).
- Social activity or factors related to life outside work considered include home-work interface (Smith et al., 2006) and sleep patterns ashore or at home (Smith et al., 2006; Parker et al., 1998; Sanquist et al., 1997; Sanquist et al., 1996).
- Demographics are often collected (Smith et al., 2006; Starren et al., 2008) and those considered explicitly in terms of effects on fatigue include experience as seafarer/as watchkeeper (Accident Investigation Board Finland, 2004; Parker et al., 1998), morning/evening type (Accident Investigation Board Finland, 2004; Parker et al., 1998; Härmä et al., 2008), and vulnerability to fatigue (Parker et al., 1998; Kongsvik and Størkersen, 2011)

Fatigue combating strategies employed by individual seafarers are also considered (Parker et al., 1998; Sanquist et al., 1996).

Health, wellbeing and performance effects of fatigue are dealt with by many of the studies. The following health and wellbeing outcomes are considered:

- Well-being at work, wellbeing on leaving work and need for recovery after work (Bridger et al., 2010; Smith et al., 2006; Smith, Lane, and Bloor, 2001)
- Stress levels (Smith et al., 2006; Smith, Lane, and Bloor, 2001) including objective salivary cortisol measurements (Smith et al., 2003).
- General, mental and physical health outcomes (Lützhöft et al., 2007; Wadsworth, Allen, and Smith, 2008; Smith et al., 2006; Smith, Lane, and Bloor, 2001; Smith et al., 2003; Accident Investigation Board Finland, 2004)

Fatigue impact on task performance is often approximated using psychomotor performance tasks, including reaction-time tasks (Lützhöft et al., 2007; Kongsvik and Størkersen, 2011), focused attention or vigilance tasks (Kongsvik and Størkersen, 2011) and categorical search tasks (Smith et al., 2003), while (Miller et al., 2003) used a comprehensive test battery. Tests are normally carried out during or following a watch. Related outcomes captured with survey instruments include cognitive failures (Wadsworth, Allen, and Smith, 2008) and effort involved in performing on board tasks (Starren et al., 2008). On-the-job alertness (Knauth et al., 1986; Ferguson et al., 2008) and sleep-related safety problems are often of ultimate interest (Hansen and Holmen, 2011), and there are measures of fatigue-related incidents and collisions at sea (Parker et al., 1998; Smith et al., 2006; Smith, Lane, and Bloor, 2001; Smith et al., 2003), or accident/near miss involvement over a defined period (Kongsvik and Størkersen, 2011; Accident Investigation Board Finland, 2004).

4.3.2 Populations studied

Populations from which samples are derived are often heterogeneous. Crew can be from a single country or multinational, and the shipping company they work for may

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operate all over the globe. The ship they are on can also be registered in a country that differs from the nationality of either the crew or the shipping company. This means that the crew of a single ship will rarely be representative of most other ships, even of a similar type. Nevertheless, crew working on a wide range of vessel types have been sampled, working in deep sea or short sea shipping, and on a large range of vessel sizes and functions. Perhaps the most useful studies are those comparing different crew types, because the same measure of fatigue will be used and the same contributors and outcomes will be considered. Perhaps the best example of this is the Cardiff Sea Study surveys, which sampled 500 seafarers in offshore oil support vessels, almost 1000 seafarers from "short sea" ferry/cargo/tankers and 350 survey responses from UK "deep sea", mini-bulkers, short-haul bulkers, containerships, reefers, tankers, cruise and fishing vessels (Smith et al., 2003; Smith et al., 2001; Smith et al., 2006). Most of the respondents were deck (49 per cent) or engineering (36 per cent) officers. Just over 40 per cent (41 per cent) worked on ferries, 25 per cent on offshore support, supply or standby vessels, and 19 per cent on tankers. Two-thirds (67 per cent) of the respondents worked on UK flagged vessels. Another example is that of Hansen and Holmen (2011), who, athough focusing on a Norwegian shipping company, studied 577 offshore fleet workers on vessels operating in all over the world.

Survey studies tend to involve larger number of crew, and are likely to involve samples that are more representative of seagoing populations than more intensive on board studies (Kongsvik and Størkersen, 2011). The latter are typically carried out on fewer numbers, especially where objective readings are taken. For example Lützhöft et al. (2007)'s study recruited 30 seafarers participate in field studies on board 13 cargo vessels over 3 to 5 days. Such comprehensive on board studies can, however, involve up to 200 crew (Sanquist et al., 1997; Sanquist et al., 1996; Starren et al., 2008), and are often focused on subgroups of crew such as bridge workers, watch officers (Accident Investigation Board Finland, 2004) and sea pilots (Parker et al., 1998). Finally, some studies are of highly specialised samples with unique challenges, such as US Navy patrol pilots (Grech et al., 2009) or barrier reef pilots in Australia (Parker et al., 1998).

4.3.3 Data collection and methods

The Cardiff Sea Study is a series of fatigue studies carried out on different types of vessels, combining data from surveys, logbooks, actigraphs, psychomotor tests and vessel motion/noise surveys. Influenced by International Transport Federation's study "Waking Up to the Dangers" (ITF, 1997) (see Appendix 3), it considers all types of fatigue influences including occupational factors, such as job support and control, training, home-work interface and health behaviours. Carried out in three phases, the study aimed to chart incidence and effect of fatigue for ship types and voyage cycles, identify optimal shift patterns and duty tours to minimise fatigue, and assess the interface between ships and installations/ports with an emphasis on the effects of fatigue on risk perception of collisions. A comprehensive multi-method approach is also evident in several other studies of fatigue at sea, which are informed by data both from large-scale postal or internet surveys, from interviews on board, and on board/on leave measurements of sleep quantity and quality and momentary fatigue (e.g. Kongsvik and Størkersen, 2011; Lützhöft et al., 2007; Miller, Smith, and McCauley, 2003). Other studies distribute comprehensive one-off surveys to crew, and combine the results with data from sleep diaries filled out while on board or on leave (e.g. Starren et al., 2008; Accident Investigation Board Finland, 2004; Parker et

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al., 1998; Sanquist et al., 1996). Sleep and fatigue on board can also be measured objectively, most often using actigraphs or ECG/EOG (e.g. Lützhöft et al., 2007). Several studies also record performance measures at different times of the day and shift.

It is not uncommon that a range of organisational, environmental and human causes of fatigue tend to be considered by studies, although there are studies focusing on single aspects, such as alertness (Knauth et al., 1986). In an alternative approach, Pollard et al. (1990) carry out inductive research on causes of fatigue and comparison of measures of fatigue in US shipboard crew.

The response rates of surveys sent out using lists obtained from unions or shipping companies varies from 7 to 30 per cent. Another way of distributing surveys is to send them to ship masters for further distribution to the crew (Kongsvik and Størkersen, 2011). For studies involving objective measurement on the ship, one or more researchers is often present on board to distribute tools and collect data (e.g. Lützhöft et al., 2007). Favourable on board participation rates may be obtained if seafarers are invited to choose a time that suits them in advance of the study (Sanquist et al., 1997). Engagement of the ship's master is important to the success of on board studies (Pollard et al., 1990).

4.3.4 Operationalization of the fatigue state

Standard self-report measures of general fatigue used by studies include Epworth Sleepiness Scale (Härmä et al., 2008; Miller et al., 2003; Accident Investigation Board Finland, 2004), the Skogby Excessive Daytime Sleepiness scale (Härmä et al., 2008; Accident Investigation Board Finland, 2004), and fatigue subscale of the profile of fatigue-related symptoms (Smith et al., 2006; Ray et al., 1992). The Need for Recovery scale (van Veldhoven and Broersen, 2003), which includes indicators of fatigue such as lack of concentration or reduced motivation for activities at the end of the day, has also been used as a proxy for general fatigue (Bridger et al., 2010).

Standard self-report measures of momentary fatigue are normally collected at regular intervals across a duty or wake period, or before and after a duty or sleep. These include the Karolinska Sleepiness Scale (Lützhöft et al., 2007; Accident Investigation Board Finland, 2004; Reyner and Baulk, 2000), the Stanford Sleepiness Scale (Miller et al., 2003), and the Samn-Perelli scale measuring broader momentary fatigue (Ferguson et al., 2008; Grech et al., 2009; Pollard et al., 1990). There is a somewhat greater emphasis on operationalizing fatigue as alertness among the sea studies, either using Likert or bipolar visual analog scales (Condon et al., 1988; Knauth et al., 1986; Sanquist et al., 1997; Smith et al., 2006). Measures of hourly fatigue have also been collected retrospectively at the end of the day using the Retrospective Alertness Inventory of Folkard et al. (1995) (Sanquist et al., 1997; Louie and Doolen, 2007). Sanquist et al. (1996) employ the relatively sophisticated concept of critical fatigue, which is informed by sleep obtained and reports of alertness. Custom measures of general fatigue are also employed, and include general fatigue resulting from a tour at sea (Kongsvik and Størkersen, 2011), fatigue at work and fatigue after work (Smith et al., 2006; Kongsvik and Størkersen, 2011), or self-ratings of fatigue at regular time intervals across a duty or while awake (Starren et al., 2008; Accident Investigation Board Finland, 2004). Attempts have been made to measure sleepiness objectively, using EOG (Lützhöft et al., 2007), although some authors often explicitly point out that self-reports are often chosen because objective measurement of sleepiness during field studies is resource intensive (e.g. Miller et al., 2003).

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4.3.5 Findings

Prevalence

Due to the heterogeneous nature of shipping, a wide variety of fatigue measures employed, and different ways of reporting them, it is rarely possible to generalize about prevalence rates, even for specific role types. This is exacerbated by use of tailored fatigue measures. For instance, half the crew studied by Kongsvik and Størkersen (2011) agreed they are worn out after four weeks on duty, but it is not clear what "worn out" means or how much it varies among individuals. Prevalence rate comparisons are perhaps most useful when they are based on widely used standardized, validated measures within single large studies, where prevalence rates for different crew types can be compared. One example is the use by the Cardiff Sea Study scores of Ray's Profile of Fatigue Related Symptoms (PRFS) throughout different phases of the project, which enabled fatigue prevalence rates to be compared for different populations, and increasing prevalence rates to be demonstrated with increasing levels of work hazards (Smith, Allen, and Wadsworth, 2007). The study also carried out a comparison of seafarers with a limited sample of truck drivers and general workers. It found that seafarers had higher PRFS levels than general workers while at work and after work, but that levels were lower than for truck drivers, both generally and while at work. Even here, however, it is not easy to validate these findings with those from other studies, which rarely employ the PRFS.

In Lützhöft et al. (2007)'s study, Karolinska Sleepiness Scale scores suggested that 3 per cent of participants had severe sleepiness (scores 8 or 9) while working. Scores over 5 were also common for participants working beyond their planned watch. Using the retrospective alertness index, 38 per cent reported decreased alertness on watch, with no difference between watches, while according to retrospective ratings employed by Louie and Doolen (2007), one third of participants fatigued 20 to 40 per cent of the time. One third of officers working 6/6 reported excessive sleepiness (Excessive Daytime Sleepiness rates over 14) (Härmä et al., 2008).

Contributors

Sleep

Sleep is almost always studied in the context of a certain watch system, and there are many more studies on sleep and shifts than those included here[3]. Although low numbers of participants were involved, the Swedish *Fatigue at Sea* study found that sleeps on two-watch ships (6/6) were rarely longer than 4.5 h, and sleep was also curtailed by those working a three-watch (4/8) system, but only for those starting their shifts at 0400 h and 1600 h (Lützhöft et al., 2007). Sleep quality was also low for these watches. For most participants, the desired amount of sleep was 8 hours, but most only got 6 or 7 h. There were indications that participants on all watches had longer and better sleeps at home than while on board, and were also less sleepy and less stressed at home. The Sanquist studies in the US concur that even watchstanders on 4/8 systems show considerable disruption to their sleep (Sanquist et al., 1997; Sanquist et al., 1996). Average sleep for watchstanders in this study was 6.6 h, also concurring with the Swedish study, but sleep was taken in fragments of normally less

[3] They are not included here because many do not measure fatigue in field or survey studies.

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than 5 h in duration. They also found that watchstanders working 0400 h and 1600 h shifts were of concern, sleeping less than 4 h in 22 per cent of 24 h periods. In contrast, 8 h sleep at home was typical, and at home there was no significant differences between watches. A sleep debt of 1.3 h per night was recorded on ship. According to Kongsvik and Størkersen (2011), an 8-8-4-4 system affords better sleep efficiency, more continuous sleep and more sufficient sleep than 6-6 systems, but there was no detectable difference in terms of fatigue or safety parameters.

Officers have been found to have worse quality of sleep than other crew members, despite getting most sleep, probably due to disruptions (Starren et al., 2008; Louie and Doolen, 2007). Lack of sleep and inconsistent sleep times are most common causes of fatigue cited by deck watch officers. Average sleep per day was mostly between 6 and 7 h, but in port this was reduced (Arendt et al., 2006). Sea pilots appear to be most challenged in terms of sleep, at least in certain contexts. While at sea pilots have reported getting 5.5 h sleep per day on average, comprising 2.5 sleeps lasting 2.2 h (Accident Investigation Board Finland, 2004; Parker et al., 1998). (At home pilots sleep in a single block.) Daily average sleep debt for pilots has been reported as 2.3 h. Pilots nap more at sea and the time to fall asleep is shorter. Another, unusual sample of marine pilots has also been studied working tours lasting up to 72 hours (Ferguson et al., 2008). Their average sleep length was 1.4 h, with an average time in bed of 1.9 h. Regular naps meant that time awake between sleep on board was on average 5.3 h. The pilots obtained total average of 5.1 h sleep a day. In a sample of ferry workers, there were much less problems associated with sleep. Reyner and Baulk (2000) reported no serious sleepiness problems among their limited sample (2 ships). There was less sleep and higher sleep distrubance (actigraphy) at sea, but this did not result in serious daytime sleepiness problems.

The effect of rotating watches has also been assessed in terms of its effects on sleep (Arendt et al., 2006). Objective sleep quality was poorer in rotaters compared to day and fixed watch shifts, as indexed by sleep efficiency and wakes. The second sleep was poorly efficient for all rotating watches, and few differences were found between different watches for those rotating.

Time of day

Circadian variation of alertness with time of day has been studies in seafarers, and alertness found to be lowest at 0400 h (Knauth et al., 1986). Accordingly, fatigue has been found to be more prevalent in bridge crew between 0400 h and 0700 h, next between 0100 and 0400 h, and then between 0700 h to 1000 h (Accident Investigation Board Finland, 2004). It was least prevalent between 1000 h and 2200 h. A second study in the same study programme found that Karolinska Sleepiness Scale ratings peaked between 0400 h and 0600 h, while levels were lowest at 1400 h (Härmä et al., 2008). Interestingly, severe sleepiness at 0400-0600 was especially a problem in the 6/6 watch system among evening types and bridge officers with high scores on the Epworth Sleepiness Scale. Generally, however, time of day, time spent awake, length of sleep, but not Epworth Sleepiness Scale ratings, were each found to relate to variation in Karolinska Sleepiness Scale ratings (Accident Investigation Board Finland, 2004).

Alertness over time has been found to increase over the course of the morning watch, and decreases across afternoon and evening watches (Accident Investigation Board Finland, 2004). Alertness improves from the start to the end of watch for first half of day, but worsens from start to end for watches in second half of day (Knauth et al., 1986).

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Other occupational, organisational and sectoral conditions

The following factors have been considered:

- *Working hours and tour length.* The Cardiff Sea Study found working hours to be the strongest predictor of fatigue (Smith et al., 2003). In fact, differences in working hours explained much of the variability in fatigue found for different types of ship. Karolinska Sleepiness Scale scores in one study were found to increase slightly as shift hours progressed (Lützhöft et al., 2007). This was especially true for participants on 6/6 system nearing the end of a 6-hour watch. Length of tour and working week have also been found to influence fatigue (Smith et al., 2003). Although job stress increased as tours progressed, there appeared to be habituation to noise and sleep improved, possibly explaining why longer tours associated with less fatigue. Fatigue on the bridge has been reported as greater if the watch is towards end of assignment (Parker et al., 1998). Karolinska Sleepiness Scale measurements have been found to increase over course of week at work (Reyner and Baulk), and subjective fatigue has been found to increase from the start to the end of a ship tour (Ferguson et al., 2008).
- *Subsector.* The more intense working patterns found in short sea (coastal) shipping are also noted by others (Starren et al., 2008). In terms of effort, coastal seafarers rated maintenance and loading tasks as highest, although navigation and watchkeeping also required moderately high effort. Mini-bulker crew especially susceptible to fatigue, reporting twice as many fatigue symptoms as other ship types, and shoring worse reaction times and lapses of attention in a categorical search task (Smith et al., 2006). For mini-bulkers, fatigue-related impairments have been found to increase rather than decrease as the tour progressed (Smith et al., 2006).
- *Psychosocial factors in the workplace.* Job demands, perceived stress and work support have been found to be selective predictors of fatigue, according to survey responses (Smith et al., 2003). According to logbook responses in the same study, fatigue was predicted by job satisfaction, job effort and sleep measures. There was a moderate association between log and survey data for respondents who filled out both. Workload is an important type of job demand. Underload and overload on watch have been found to result in higher fatigue ratings for US Navy patrol crew (Grech et al., 2009). At the start of patrol, low workload was associated with fatigue, but at the end of patrol, high workload was associated with fatigue.
- *Position.* Officers report more job demands and stress than ratings, but also more interest in job. The latter may explain why there is little difference in fatigue between the two groups, even though officers also report worse sleep quality (Smith et al., 2003). According to qualitative interviews with 13 companies agreed that officers on the bridge always has fatigue-sensitive tasks, but no company experienced fatigue as a problem "during normal conditions" (Lützhöft et al., 2007). The study of coastal shipping by Starren et al. (2008) suggested fatigue differences according to role, but that role interacts with on- and offshore activities in complex ways to affect sleep and fatigue. For masters and first officers, fatigue was found to be worse on days when they are both in port and offshore, even though sleep is obtained also on these days. For engineers, fatigue did not decrease after work, but it did for deck crew. The data also implied that some watch systems suit some roles better and others worse. Other studies suggests that masters and first officers may become more fatigued than others towards the end of the duty (Louie and Doolen, 2007).

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- *Physical environment.* Noise has been reported as the biggest cause of fatigue among offshore fleet workers (Hansen and Holmen, 2011).
- *Shift system.* In line with the findings on sleep, 6/6 watch systems are more associated with general fatigue symptoms than 4/8 or other (mostly 12/12) (e.g. Accident Investigation Board Finland, 2004).

Activity, diet and health

While there are some considerations of health as an outcome (not least by the Cardiff Sea Study), health does not appear to have a high profile as a contributor to fatigue at sea.

Demographics and life outside work

Age is an important predictor of fatigue-related symptoms; when operationalized in this way, fatigue has been found to increase with age (Smith et al., 2003). However, when operationalized as Need for Recovery, fatigue does not appear to depend on age (Bridger et al., 2010). Likewise, there are no significant difference in fatigue between younger and older halves of sample when retrospective ratings of fatigue on board are given by deck watch officers (Louie and Doolen, 2007). Other studies find that greater age is associated with better vigilance performance (Miller et al., 2003). Where different shift systems have been found to have no main effects on fatigue, there may be effects in combination with time of day and age, or with time of day and circadian type (Accident Investigation Board Finland, 2004). On a 4/8 system, for instance, 50-62 year olds were sleepier than 30-49 year olds, both at night and in afternoon, whereas on a 6/6 system no differences were found between the two age groups. A regression analysis by Härmä et al. (2008) finds that Karolinska Sleepiness Scale ratings related to several factors including interactions of watch system with age and morning-eveningness.

Lützhöft et al. (2007) found that non-Swedish participants rated their sleepiness lower, but reaction times were much slower. This suggests that there may be important cultural differences across nationalities which affect their perceptions of fatigue.

Factors in combination

An overarching regression analysis of the Cardiff Sea Study data finds that working hours, job demands and perceived stress were selective predictors of fatigue, followed by age, vibration and noise exposure, work support, and having to stand watch (Wadsworth, Allen, McNamara, and Smith, 2008). However, the best predictor was the combined effect of negative job characteristics, predicting not only fatigue but health status. The greater number of job-related risk factors was associated with greater fatigue i.e. there was a dose-response effect. This important finding suggests that when different factors are present together, the effects on fatigue are additive (Wadsworth, Allen, and Smith, 2008). Furthermore, the *quality* of the job may be at least as important determinant of fatigue than quantitative job factors that are usually considered, such as working hours.

Operationalising fatigue with the Need for Recovery scale, Bridger et al. (2010) found that fatigue was associated with poorer sleep quality, noise and nightshift. Frustration at work was strongly related to fatigue, even for those who carry out a lot of physical activity. Work-related fatigue found to accumulate over time on board ship for those continually exposed to high demands. This study again implicates the importance of job quality.

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4.3.6 Outcomes

Health and performance outcomes are considered. In terms of near misses and accidents, these may often be too low in number to be linked to fatigue, and accidents at work are more related to aspects of the physical work environment. The Cardiff Sea Study finds a strong link between fatigue and poorer cognitive and health outcomes, with fatigue being the factor that accounts for the largest proportion (10-14 per cent) of variance in these outcomes (Wadsworth, Allen, and Smith, 2008). In other studies palm-top tests have showed that reaction times after a night shift were significantly higher and more variable than following a day shift (Lützhöft et al., 2007). There was also a slight tendency to higher reaction times for two-watch participants. In terms of actual safety parameters however, watch comparisons can fail to reveal differences (e.g. Kongsvik and Størkersen, 2011), and other studies show little difference in response time on cognitive test over time of day (Ferguson et al., 2008). This is no doubt linked to the fact that people are good at conserving performance seen as important for safety, in the face of high levels of fatigue. Given this, perceptions of seafarers may be a more sensitive way to detect differences. For instance, one study showed that nineteen per cent of 6/6 watch versus 12 per cent of 12/12 watch, respectively, reported sleep problems affected their ability to work safely during the preceding year (Sanquist et al., 1997). In addition to performance, outcomes are also measured in terms of falling asleep while on watch. One study finds that 7.3 per cent of officers on a 6/6 watch had nodded off during work hours, cf 1.5-2 per cent on other watches (mostly 4/8) (Accident Investigation Board Finland, 2004). Of all officers, 40 per cent said they had been close to nodding off on watch in last 5 y, and 18 per cent had nodded off at least once during watch.

4.3.7 Summary

The study of seafarers is complicated by the many different roles, vessel types, port call frequencies, tour lengths, and crew, vessel and flag nationalities. Studies may survey a large number of crew, or there may be more intensive measurement of a few crew on a single vessel. Generalised fatigue has been operationalised using a range of standard measures, including the Epworth Sleepiness Scale. Self-reports on momentary fatigue or sleepiness are also common. However, attempts to generalise about prevalence rates are complicated by the heterogeneous nature of shipping and the wide range of fatigue measures employed. One study does suggest, however, that seafarers generally report fewer fatigue symptoms than do truck drivers.

Many studies on the causes of seafarer fatigue have tended to focus on the link between different watch patterns and sleep, especially for watch officers. The sleep patterns of seafarers are relatively well documented, and both sleep quantity and quality are poor, especially for those working the popular 6/6 watch. Average total sleep lengths per day seem to center around 6 to 7 hours for many crew, but this sleep is often taken in two or more spells. Continuous sleep periods of desired length are rare. Some recent studies are impressively comprehensive, accounting for a wide range of contributors to fatigue, including port work, tour length, physical working and sleeping environment, automation, and traditional organisational factors such as training and psychosocial conditions. Working hours are claimed by some to be the strongest predictor of fatigue. Although it is not clear whether fatigue increases as tours progress, most studies find that fatigue increases slightly as shifts progres, an effect that it is tempered by time of day. Fatigue and sleepiness levels have been shown to vary with circadian lows, especially between 0400 h and 0600 h. Circadian

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effects at this time may be revealed by the presence of other factors, such as working an unfavourable watch system and individual differences. In terms of different watch systems, the traditional 6/6 system is often linked to poorer sleep, although this is not always manifested as increased fatigue or sleepiness on the job. Seafarers – especially officers – may be skilled at compensating to maintain performance, but the consequent latent performance effects are not clear. Some studies indicate that performance maintenance may take a toll on seafarer health in the long term. Effects of role or position on a ship on fatigue are complex, and in addition to job motivation, may be influenced by ship function or factors such as whether or not the ship is in port. Coastal shipping work is more intense in terms of effort, and mini-bulker crew are especially susceptible to fatigue. Negative job factors, such as workload and lack of support have been found to be additive in terms of their effects on fatigue. Health and exercise have also been considered as possible *contributors* to fatigue, although perhaps to a lesser extent than for road and rail studies. Findings so far do not implicate health as a strong contributor to fatigue at sea. Recent findings imply that the quality of the job may be at least as important as quantity (in terms of working hours), and there is a need for increased focus on job quality. Some important contributors may also have been overlooked, such as off-the-job factors, the increasing burden from different types of work to be carried out by individual roles and increasing concerns about reduced manning levels (Akhtar and Utne 2014).

Fatigue effects on performance are often approximated with surveys of performance or cognitive tests on board. Perhaps not surprisingly, such tests often fail to reveal the effects of fatigue, and self-reports about how seafarers feel their performance has been affected may be more informative. Such reports may capture the totality of increasing cognitive lapses or slowness during real work, which may go undetected by short-lasting cognitive tests for which the participant may be primed. Reports on falling asleep on watch are another way to tap into performance effects, although there is a need for standardisation in terms of a time period over which respondents are asked to estimate how many times they have nodded off.

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5 Study assessment

We begin out assessment of the selected studies by considering how they have approached the concept of fatigue.

5.1 Operationalisation of fatigue

According to our definition and conceptualization of fatigue, described in Sections 1.1.1 to 1.1.3, we need to measure both psychological and physiological aspects of fatigue in order to understand the *state* of fatigue. In order to understand the fatigue *process*, we need to characterize the form, dynamics and content of exertion, in addition to actual and latent performance. Most of the studies included here do not give explicit accounts of how they operationalize fatigue. Given this, one way to proceed is to make inferences by looking at how studies measure the fatigue *state*. Likewise, which contributors to and outcomes of fatigue are measured will inform us about their treatment of the fatigue *process*. In section 1.2 we outlined nine questions that would help us understand to what extent the "whole" of fatigue has been considered by the different studies, and help identify aspects of fatigue that may have been overlooked. The following account considers how the fatigue state and process has been operationalized by answering these nine questions (in italics below).

5.1.1 The fatigue state

Many of the road studies (15 out of 39) employ the Epworth Sleepiness Scale (ESS) to measure fatigue, and most do not employ any other measure of fatigue. The ESS asks respondents to report on how likely they are to fall asleep in various life situations, such as sitting in front of the television. It is a measure of general sleepiness, since no time period is defined on which operators should base their response. The ESS is widely used and validated, and thus allows researchers to compare results for their sample with those from other occupational samples. It also allows cases of excessive daytime sleepiness to be expressed in terms of the percentage of the sample scoring above 10 (Johns, 1991). The ESS appears to be particularly appropriate when considering the effects of sleep.

According to our definition, sleepiness is a core aspect of the psychophysiological state of fatigue, but it does not capture all aspects of mental exhaustion that may affect performance, e.g. psychosocial factors may increase exertion and consequently work-related fatigue, without increasing sleepiness. In addition, problems related to acute sleepiness while operating through circadian lows, and occasional episodes of severe sleep debt will go undetected using the ESS. When wishing to assess fatigue in an operating population, it may therefore be fruitful to supplement ESS with:

- Measures capturing broader aspects of general fatigue that have been validated for occupational samples, such as the Swedish Occupational Fatigue Index (Åhsberg, 2000), the Checklist Individual Strength (Bültmann et al., 2002) or the Profile of Fatigue Related Symptoms (Ray et al., 1992);

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- Standardized measures of acute sleepiness or fatigue during or after work, such as the Karolinska Sleepiness Scale (Åkerstedt, Anund, Axelsson, and Kecklund, 2014) or the Samn-Perelli fatigue measure (Samn and Perelli, 1982).

A further criticism of the ESS is that it does not assess general fatigue encountered while driving. This may partly explain why several of the road studies do not employ standard, validated measures of fatigue, but one-off measures that can be tailored towards driving and increase the safety-relevance of the results (e.g. How often do you drive while tired? How often do you find concentrating lapsing while you drive?). However, lack of standardization means that valuable comparisons of different operator populations cannot be made. Indeed it seems that there is a need for a widely used, validated, standardized measure of the various dimensions of fatigue experienced while driving or operating, based on fatigue-related experiences or symptoms that most can relate to. Attempts have been made to promote such scales, most notably by Matthews et al. (2009), but they are not used by the road studies included here.

In contrast to the road studies, few of the rail studies (3 out of 23) employed the ESS, and there were otherwise few attempts to account for general or chronic fatigue. This reflects that studies on rail operators tend to be concerned with the effects of demanding schedules on acute fatigue during a work period. Out of 23 studies, 17 used a standard measure of acute fatigue. Of these, seven used the Samn-Perelli measure of broader fatigue, six used the Karolinska Sleepiness Scale (KSS), two were based on alertness, one was based on a visual analog scale for fatigue, and one used the Swedish Occupational Fatigue Index (SOFI). Acute measures are usually taken before, during and/or after a work period or shift. The rail studies rarely use two or more complementary scales, either of acute and general fatigue / sleepiness, or of sleepiness and broader fatigue. Several of the road studies interested in acute effects of shifts or task effects also used acute measures of sleepiness or fatigue, but in both the rail and road studies the use of different standardized scales by different studies (or failure to use complementary standardized scales) limits the extent to which we can compare the findings. The situation would be improved if researchers using custom measures of fatigue supplemented them with standard scales of choice to promote progress in the study of transport operator fatigue. A recommendation to employ KSS and Samn-Perelli scales together when measuring acute fatigue, for instance, would improve matters.

Among the 24 sea studies, there is a more balanced consideration of acute and accumulative fatigue. Moreover, several studies (7 of 24) combine measures of both types of fatigue. This reflects the more comprehensive nature of some of the studies of fatigue at sea. Often standardized measures are combined to capture different aspects of fatigue, such as the ESS and KSS (Accident Investigation Board Finland, 2004) or the Profile of Fatigue-Related symptoms and onboard measures of alertness (Smith et al., 2003). Some studies capture acute and accumulative fatigue by recording acute sleepiness or alertness every few hours over days or weeks (e.g. Reyner and Baulk, 2000). Some of the studies also account for the way in which fatigue develops over time, reflecting a focus on circadian lows (someone must always operate between 0400 h and 0600 h at sea) and different watch systems. There is also a focus on fatigue both on and off the job. Notably, several studies operationalise fatigue as alertness, with authors arguing that this is a highly safety-relevant way to measure acute fatigue. However, as in the other sectors, there are customized measures and studies using a wide range of different measures, such that

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there is no widely used standardized measure and comparisons are difficult. Few of the sea studies account for the varying dimensions of the fatigue experience.

Only a few of the road, rail and sea studies attempt to measure physiological aspects of fatigue. This is not surprising given the high invasiveness and resource intensiveness of such measurements and compared with issuing surveys. Another problem is that while survey questions can measure fatigue explicitly, physiological measures are only implicit measures. Since there is no one best proxy measure for fatigue, a wide range of measures are used (e.g. heart rate, hormone levels, ear temperature, blood pressure or vision/eye movements, EEG and EOG), making comparisons difficult. Low participant numbers and lack of certainty about the meaning of physiological measures in relation to fatigue means that conclusions drawn from such measures are often less than solid.

Despite these drawbacks, if we accept that fatigue is a psychophysiological condition then we will never completely understand it unless we can measure its physiological indicators, not least because doing so allows us to observe the fatigue state independently of the fatigued person, who may not be able to accurately report one his or her fatigue. Matters would again be improved if researchers could achieve consensus on standard measures for physiological fatigue in particular situations. Naturalistic experiments described by two of the road studies and one of the rail studies included here, also suggest how we can progress. These involve objective measurement of aspects of physiology that can be observed while the drivers were operating, e.g. percentage of time spent driving with droopy eyes. Technology that allows such measurements is continuously improving and studies should be encouraged to consider such measures in the future (Wilschut and Caljouw, 2009).

We can now answer the first four questions posed in Section 1.2.

Is the experience of the fatigue state itself measured along several dimensions?

Most studies ask operators to report only on sleepiness, or on a one-dimensional scale of fatigue such as the Samn-Perelli checklist. Thus most studies do not use self-report scales to capture simultaneously the different dimensions of fatigue, such as emotional, motivational, or cognitive fatigue as well as physical fatigue or fatigue symptoms, and sleepiness. Measuring the different dimensional aspects of fatigue may reveal interesting dissociations in fatigue dimensions, or dimensional profiles that are characteristic of different operator roles. This is exemplified by studies employing the Swedish Occupational Fatigue Index, which measures different dimensions of acute fatigue. Standardized scales are also available that measure different dimensions of generalised fatigue, and have been validated for use in occupational samples (e.g. Bültmann et al., 2002). Most studies on the road and rail sector until now have been focused on the problems of acute fatigue, but there is also a need to focus on the interrelated health and safety effects of accumulative fatigue.

Do studies consider both psychological and physiological aspects of the fatigue state?

Most studies consider psychological aspects by asking operators to report on how they have experienced fatigue, either generally or during the course of a specific work period or shift. While there are some studies that supplement self-reports with physiological measurements, they are few, based on low numbers, measure fatigue only implicitly, and are often inconclusive. Naturalistic studies are promising in that they allow objective observations of the fatigue state, albeit implicitly.

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Do studies account for sleepiness explicitly in relation to fatigue?

There are few attempts to measure sleepiness in relation to broader fatigue, and thus few attempts to account explicitly for variations in sleepiness versus other dimensions of fatigue. In addition, there is little evidence that studies here consider the role and relative importance to safety and health of sleepy versus non-sleepy fatigue.

Do studies employ measures of fatigue that are valid and useful for occupational samples, and which thus allow for comparisons with other operators or occupations?

On the whole the answer is yes. However, comparisons are limited by the use of different measures by the different studies. Widespread use of a standardised battery of fatigue measures would enable more comparisons to be made and advance progress in the field.

Which populations are in focus, are they representative, and are they the ones that are most at risk for fatigue, or whose behaviour has greatest implications for safe transport operations?

Studies in the road sector have traditionally considered long-distance truck drivers, but there is increasing recognition that local drivers have unique fatigue-related challenges, which may be no less severe. There are several studies on bus driver fatigue, but they overlook the problem of split shifts that many of them work. In this branch of the road sector and others, an increasing need to compete places increased work pressures on drivers, but there has been little explicit consideration of the effects of this on driver fatigue. There are few studies of taxi drivers, even though their working conditions exposes them to high levels of fatigue. The organizations in which locomotive engineers work are characterized by less heterogeneous working conditions, but there may be important differences between public and private companies, and between passenger and cargo transport, and only one or two studies have addressed this issue. In particular, there is a need to study samples of locomotive engineers that are representative of national populations, if one is to assess the problem of locomotive engineer fatigue in particular countries. This also applies to sea studies, although due to the heterogeneous subsectors in the maritime sector, one may rather wish to generalize to vessel or subsector types.

5.1.2 The fatigue process

Contributors

Different contributors studied by research in different sectors is exemplified in Table 2. This table can be used to help answer the following question from Section 1.2:

Do the studies account for the complete system of various interacting fatigue causes, in particular actual sleep history, time of day and time-on-task, but also organisational / sectoral influences, environmental influences, individual traits and states, and the influence of factors anchored in life outside work?

A comparison of Table 2 with the possible influences on fatigue set out in Figure 2 suggests that many of the possible influences have been considered. Schedule-related sleep problems are relatively well studied in all sectors, with several studies in the rail and sea sectors documenting actual sleep patterns over several days or weeks in relation to fatigue. Studies in these sectors are understandably more structured. In the rail sector there is a focus on problems associated with night shifts and early starts, whereas in the sea sector the focus is also on the effects of different watch systems on sleep and fatigue. While schedules are rather more erratic in road transport,

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especially in goods transport, there are cases where routine schedules are worked (e.g. local bus), yet the effects of different rotor systems do not appear to have been studied as systematically. Road transport research is rather focused on mapping the working and sleeping patterns of long-distance goods drivers, and linking those patterns to sleep and fatigue effects.

Table 2. Examples of different types of fatigue contributors studied that contribute to fatigue, according to sector of fatigue study

Category	Road	Rail	Sea
Sleep and schedules	Sleep quantity/quality Napping Actual schedules Sleep opportunities Coping with sleep	Sleep quantity/quality Napping Planned and actual shift schedules Length of average shift Schedule regularity Schedule predictability Rotation patterns Number of night starts Time between shifts Sleeping conditions	Sleep quantity/quality Sleep consistency Planned and actual shift schedules Sleep opportunities Watch system Watch start times Watch rotation Sleeping conditions
Occupational and sectoral factors	Working hours Psychosocial work factors (demands/workload, control support) Physical workload Cargo type Perceived colleague norms related to fatigue Break times Economic pressures Employment contract Payment system Employer-employee relations.	Working hours Psychosocial work factors (demands workload, control support, conflict, job satisfaction, job stress) Physical workload Physical working environment Training Length of service Time in limbo Break times Overtime Swapped shifts Share of time spent driving	Working hours Psychosocial work factors (demands/workload, control support, conflict, job satisfaction, job stress, job security) Physical work environment Port frequency Port turnaround Duration of voyage Time zone Fatigue knowledge Physical workload Physical environment (motion, noise) Time use / non-watch work Fatigue prevalence on vessel Automation levels Adherence to (safety procedures)
Health-related factors	Health status Dietary habits Physical activity Sleep disorders Body-mass index	Health status Alcohol use Medicine use Caffeine use Body-mass index Sleep apnea	Dietary habits Physical activity Sleep disorders/apnea Body-mass index Medicine use Sea sickness
Non-work factors	Social activity Life outside work	Commuting time Social support from friends and family	Work/non-work interface Sleep patterns ashore/home versus onboard
Demographics	Age Socioeconomic status Educational level Domestic status	Age Socioeconomic status Educational level Domestic status Partner's employment status No. of dependents Circadian type	Age Socioeconomic status Educational level Experience as watchkeeper Circadian type Fatigue proneness

Many studies have also considered various occupational conditions (other than schedules) and conditions inherent to the sector in which operators work. However, there is a need for greater explicitness about the different challenges faced by subsectors within each main transport sector. The independent truck driver-owner who searches speculatively for cargoes to deliver may face different challenges than the driver employed by a large organization transporting hazardous goods and clearly

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prioritising health and safety. The fatigue-related challenges for the crew of a small fishing boat facing a lot of physical work, extreme weather and irregular sleep patterns will be different to those faced by the crew of a large oil tanker e.g. high level of automation, monotonous work, and inadequate staffing. There are good reasons to believe there are direct links between fatigue and different payment systems, contract types and competition conditions that characterize particular subsectors. Studies have attended to these problems, but there tend to be correlations between these factors and fatigue, rather than stark comparisons of different subsectors. Research may do well to exemplify qualitatively different challenges explicitly for organisations and regulatory authorities by presenting comparative cases.

On a related note, studies increasingly address links between the quality of work and fatigue, as researchers recognize that it is not just the quantity of work that is important. This is in line with our definition of fatigue, which states the following:

"Fatigue is…caused by exertion…described by the value and meaning of performance to the individual; rest and sleep history; circadian effects; psychosocial factors spanning work and home life; individual traits; diet; health fitness and other individual states; and environmental conditions."

It is clear that the quality of work is important to exertion and ensuing fatigue, especially in relation to the value and meaning of performance to the individual. In most cases safe driving or watchkeeping will be a task that is highly valued by operators, but it must be seen in the context of the whole job, which may not be valued. Several studies have attempted to account for motivational aspects of the whole job by accounting for the role of psychosocial work factors describing job demands and resources available to cope with them. However, there has been little consideration that having to maintain performance of the main operating task when one faces high (or too few) demands and/or is not engaged in the whole job can be particularly fatiguing, and may lead to severe latent performance decrements with risks to health and safety. Where this leads to burnout there may be a downward spiral, since disengagement from work is a main symptom of the condition (Demerouti, Mostert, and Bakker, 2010).

According to our definition, the quality of life outside work may also have effects on fatigue at work, and this may be a contributor that has been overlooked. Social activities, domestic commitments and health-related habits during the time outside work will also undoubtedly influence fatigue at work, in the shorter and longer term. Studies have only paid limited attention to these factors, perhaps because there is little the organization can do about them. Nevertheless, if one accepts the definition in Section 1.1.1, then contributors span work and home life. One will only be able to control fatigue to a limited extent if one ignores contributors from life outside work. Ways in which organizations can legitimately address aspects of operator's lives outside work have been recognized (Phillips, 2014b).

Outcomes

Different contributors studied by research in different sectors are given in Table 3, which can be used to help address the following questions:

To what extent is safety-relevant performance considered?

It is difficult to link fatigue explicitly to near misses and accidents, particularly in the rail and sea sectors, where such incidents are less common or inadequately reported.

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Improved reporting of near misses would improve the extent to which we can assess fatigue as a cause, especially in the rail and sea sectors.

The effects of fatigue on safety performance is more usually indexed by charting incidents of drowsiness or actual falling sleep while operating, often by self-reports, although it is difficult to be certain about the reliability of these reports. Our own studies suggest that drivers recall more incidents of sleep during periods of driving that have occurred in the more recent past. Studies that ask whether respondents have *ever* slept while operating are therefore least reliable and difficult to compare. It is important to consider the time scale in question when comparing reports, and again standardization would help.

Table 3. Examples of different types of outcomes of fatigue studied, according to sector of fatigue study.

Type of measure	Road	Rail	Sea
Self-reported	Drowsy driving episodes Sleeping behind the wheel Effects of fatigue on driving Burnout Shiftwork disorder Fatigue-specific health General health status Psychosomatic complaints Rule breaking behaviour.	Mood Work/home balance General health Wellbeing Shiftwork disorder Need for recovery from work Frequency of mistakes / shift Near misses at work	Wellbeing Health (general, mental, physical) Need for recovery from work Sleep or sleepiness on watch Stress Cognitive failures Effort involved in on board tasks Alertness Sleep-related safety problems
Objective	Operational driving measures Psychomotor tests Fatigue-related critical incidents General near misses General accidents Blood pressure Blood assays	Psychomotor tests Sickness absence Operational measures (braking, acceleration etc.)	Stress hormones Psychomotor tests General incidents General accidents

However, naturalistic studies on truck drivers have recently been able to link fatigue to actual safety incidents by conducting retrospective assessments of fatigue parameters in the lead up to such incidents (e.g. by observing driver drowsiness). Naturalistic studies involving systematic observation of driver drowsiness may more accurately capture the frequency of "microsleeps" that the driver may not recall, but which will have clear effects on safety performance. Such studies will give a better idea of the extent to which performance is affected by sleepiness than driver self-reports of actual sleep.

Do the studies consider a range of performance implications, particularly attention problems in low control/underload situations, but also mode errors and effects on fatigue of more complex faculties, including increased reliance on mental schemas?

Attempts to capture directly the effects of drowsiness and broader fatigue on psychomotor functioning have been made using portable psychomotor vigilance tests, but these tests do not represent real operator performance in natural situations. Retrieval of operational parameters describing driver performance in terms of smooth braking, turning or accelerating, for example, may more accurately describe deterioration in psychomotor and higher cognitive performance. Use of such data is becoming more feasible, at least for the studies of fatigue in road and rail.

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The way in which fatigue affects more complex faculties has yet to be directly considered. For example, fatigue may lead to increased dependence on mental models that represent routine situations. On a stretch of rail track, for instance, the alert locomotive engineer will continually check signals, speed limits and other indicators in the track environment in order to validate or modify his or her mental model for that stretch of track, even though the stretch of track may rarely change. The fatigued operator, however, will tend more to rely on his or her mental schema, and there will be less checking with the external environment. In deviant situations the results could be catastrophic. Operationalizing such performance effects in order to capture them is a challenge for field studies.

Do the studies consider motivation and latent performance effects, including momentary decrements, or decrements to the performance of tasks following on from the primary task? In particular, do they consider the safety implications and longer term health costs of chronic fatigue?

Studies generally appear to be lacking in both these areas. We have already noted that having to maintain performance when disengaged from the job may lead to extreme latent performance decrements, which could manifest themselves as inadequate safety checks, following a driving shift or watch, or as momentary decrements during operation. The latter may be captured by recording operational performance parameters. Studies would thus do well to focus more on the use of such parameters as measures of performance, and in addition pay more attention to the costs of having to maintain vigilance performance on tasks subsequent to the main driving or watch task. There is also a need for more explicit focus, across sectors, on the longer term health costs of chronic fatigue, particularly in relation to safety performance.

5.2 Methodology

Generally, the data collection methods used are those that are best suited to the samples of interest. Operators are surveyed where they are best accessed: by post, through their organisations or unions, or where they are operating. Truck drivers are surveyed at rest stops, terminals and health services, locomotive engineers at depots or while they are operating, and seafarers while they are resting or working onboard. Across sectors, the studies exploit a range of data collection methods, including surveys, interviews, sleep logs, work/activity diaries, actigraphs and performance tests, and several studies combine them. However, the naturalistic approach recently taken by field studies in the road sector could be usefully applied in rail and sea studies, by taking video recordings of operators and watchstanders in their natural settings in order to make retrospective assessments of fatigue. As we have also noted, increased use of operational performance parameters would be beneficial in road and rail research. It may also be possible to identify corresponding indicators of bridge crew performance.

Finally the US national survey on fatigue has been informative in terms of occupational comparisons. Similar approaches by other countries would also be useful, and allow international comparisons of fatigue prevalence. Studies taking a broad approach to fatigue in the industry are highly informative, e.g. in the UK maritime industry, the Cardiff Sea Study; Gertler's studies in US rail; and Williamson's studies in Australasia. One of the advantages of such studies is their ability to consider how framework conditions contribute to fatigue in particular subsectors. Knoweldge on fatigue would be increased if similar approaches were taken in a broader range of countries.

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5.3 Knowledge, knowledge gaps and fatigue risk management

The remainder of our discussion is structured using the modified fatigue-risk trajectory given in Table 1. This is useful in that it helps identify how existing knowledge informs risk assessment in practice, and where more research is needed.

5.3.1 Determinants of fatigue

According to the expanded trajectory, determinants of fatigue are described by work time, work quality and non-work life quality. Advances have been made by the road studies as far as understanding the different determinants of fatigue. In particular there is an established understanding of the importance of work time. Road, rail and sea studies have established that operators exposed to long work periods and restricted sleep opportunities experience increasing fatigue both within a shift, and across successive shifts, and these effects are tempered by time of day at which the shift is worked. Planned and actual schedules worked by professional drivers, locomotive engineers and watchstanders at sea have been studied, and suggest that in many cases there are long hours and limited sleep opportunities. Schedules worked by long-distance goods drivers are not easy to characterize, but they are often irregular, being influenced by daily events and by the need to exploit the limits of inflexible driving hours regulations to the full. Bus drivers and local goods drivers face their own schedule-related challenges that may contribute to fatigue. The work of locomotive engineers is typified by long, irregular hours at all times of the day or night. Watchstanders work more regular watch systems, but there may be considerable non-watch work, which restricts sleep still further and which may add to fatigue.

Work quality has been studied in addition to work time, in terms of the varying degree of demands and support experienced, or in terms of different pay systems and employment contracts. Sea studies show that the effects of different negative job factors (various demand and support factors) have additive effects on fatigue and health outcomes. There is no reason to believe this would not be the case in other sectors. Physical work quality has also been studied in terms of the task analyses and physical work conditions. Several studies imply that tasks that are secondary to the main operating task might also contribute to fatigue. Given this, it is important to account for secondary tasks may be hidden from organisations, e.g. drivers helping load or unload at depots, even though it is not part of their formal job description. Generally there is a greater need to look at the psychosocial and physical quality of work, and how this interacts with the quantity of work to cause fatigue. We have yet to form a coherent picture of which are the most important challenges for operators in different subsectors. In addition, we are only beginning to understand the contribution of non-work life to fatigue on the job. One study in the rail sector implies that social wellbeing may be a key mediator of the effects of the job on fatigue, and this idea should be explored further. In particular organisations can do much to influence non-work life at sea, so a greater understanding of its importance for fatigue is required.

5.3.2 Actual recovery from work

There is good evidence that as the result of work time demands, many drivers, locomotive engineers and watchstanders get too little sleep. A cumulative sleep debt

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due to work is well established for many transport operators, especially for seafarers who rarely get enough sleep in one continuous bout on board. Operators are more likely to suffer from sleep deficits when working shifts starting in the night or early in the morning. The cumulative effects of such shifts are associated with severe fatigue.

Another aspect of actual recovery from broader fatigue at work receiving little consideration is that recovery which occurs during non-work wake time. Evidence suggests that physical and psychological detachment from work is an important aspect of recovery from task- and sleep-related fatigue, and this will also influence the amount of sleep taken within a given opportunity for sleep (e.g. Demerouti et al., 2004; Demerouti et al., 2012). Many truck drivers, bus drivers, locomotive engineers and seafarers spend considerable time away from home, and for these people the organization may have a large influence on both the quantitative and qualitative nature of non-work wake time. In addition need for recovery scales are available to help individuals and organisations monitor recovery during non-work wake and sleep time (Sluiter et al., 2003).

Although several studies collect data on breaks at work, no clear pattern has emerged concerning the extent to which breaks are actually taken or whether they are of sufficient quantity or quality for recovery from task-related fatigue. Some studies suggest that the benefits of breaks are only temporary, and that in practice operating hours regulations or other job-related logistics may mean that operators have little control over their breaks, may forego them in order to make up for delays, or take them too near the start and end of a work period for optimal recuperation.

5.3.3 Reports of fatigue and behavioural symptoms

The road studies afford some interesting comparisons of generalised sleepiness symptoms measured using the Epworth Sleepiness Scale. One study suggests that in very general terms, general sleepiness among seafarers may be less severe than for truck drivers (average ESS score). Further progress in this area is needed and could be achieved in two ways. Firstly, by producing tables of average scores and shares of samples scoring 10 or over (excessive sleepiness), to allow researchers, practitioners and managers to benchmark their samples against similar operator populations. Secondly, by greater use of the Epworth Sleepiness Scale (especially in the rail sector), alongside other standard measures of (i) acute sleepiness and (ii) acute and generalized broader fatigue. The Karolinska Sleepiness Scale has also been used by many studies, across sectors. An attempt to review, compare and contrast scores found for different samples in different sectors would also be informative. The Karolinska Sleepiness Scale could be included as part of a standard battery to measure acute sleepiness. Likewise, the Samn-Perelli scale appears to be the most widely used standard measure of broader acute fatigue. Inclusion of a measure of broader general fatigue would also help dimensionalize the experience of fatigue, and reveal important differences between operators in different sectors and subsectors in terms of the cognitive, emotional, motivational or physical nature of fatigue. This would also be usefully linked to different workload aspects, as has been studied using NASA-TLX.

The road studies imply that the way fatigue is operationalized may be key to subjective evaluations of fatigue. For example, fatigue operationalized as sleepiness is reported less by local drivers working in intensely stimulating environments, than by long distance drivers subjected to long periods of monotony, even though levels of broader cognitive fatigue and safety-related decrements may be similar in severity.

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There may be analogous situations in the rail and sea sectors, although they have only been studied to a limited extent. Thus for instance, locomotive engineers involved in shunting operations in busy station areas may face challenges that are qualitatively different to those faced by intercity passenger train drivers, or those employed on small fishing vessels may face different problems to those working international cruise passenger routes.

The identification of common signs of operator fatigue, or field studies of job-related actions that typify fatigued operator states would help organisations monitor operator fatigue, and provide triggers for countermeasures. There is little evidence that the studies included here deal with this issue in any great depth, and this may also be a fruitful area for future research. Informal behaviours used by seafarers to inform colleagues that they are fatigued, such that they can help compensate and maintain performance, have been discussed (Dawson et al., 2012), and formalization of these behaviours may help prevent the deleterious effects of fatigue on performance. An open reporting culture would be required for effective risk monitoring at this level of the fatigue-risk trajectory.

5.3.4 Fatigue errors, incidents and accidents

The effects of fatigue (general tendency to increase across a shift, or cumulatively across shifts) often do not appear to manifest themselves clearly in driving performance, even after 8 or 9 hours of driving, although greater use of operational parameters in studies may reveal important latent performance effects. The lack of performance effects is testament to the abilities of operators to conserve performance at all costs, although studies have not assessed the range or extent of these costs, in terms of either health, or other aspects of performance in the short or long term. Many of the findings on the experience of fatigue and links to performance may be applied to other operators subjected to long monotonous operations, such as locomotive engineers and bridge watchkeepers.

In the case of drivers on the road, poor sleep is linked to both sleepiness at the wheel and accidents. There is also robust evidence about the sleep-related problems of trips beginning very early, or trips that require driving through the night. Much of this evidence is strong enough to allow schedulers to make fatigue risk predictions and avoid many of the worst sleep-related risks faced by drivers; evidence-based software is available to help them do this. A major factor to be considered is the interaction between sleep history, time on task and time of day. These conclusions, though largely based on studies on professional drivers may and are being applied across sectors.

However, there is relatively little understanding of the dynamic interactions between poor sleep and health and psychosocial pressures, and how these interactions contribute to chronic fatigue and performance decrements or organizational outcomes, such as turnover or sickness absence, in the longer term. Attrition from the industry due to fatigue may be very high, and so the industry may in many cases not pay for, or even be aware of, the long-term costs of the fatigue it imposes on its operators. Longitudinal studies and more extensive mapping of the effects of accumulative fatigue and burnout of operators on performance would help highlight these problems.

Finally, in terms of safety performance, invasive cognitive tests often fail to reveal the effects of fatigue. Naturalistic studies are starting to give a better picture about the

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share of time over which drivers drive in a dangerously fatigued state, and they imply that a small fraction of fatigued drivers may be responsible for a disproportionately high share of risky driving. Greater use of operational parameters as measures of performance would be informative. In particular, attempts to link fatigue to operational parameters for various professional drivers on particular stretches of road, as exemplified by Dorrian et al. (2007) in the rail sector, would inform about latent performance costs in terms of strategic adjustments or momentary lapses. It would also help convince managers and organizations about the business benefits of reducing fatigue (e.g. fuel economy).

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6 Conclusions

In conclusion, we make the following points about assessment of the fatigued state by the studies included here:

- Our understanding of fatigued states in transport operators is limited by studies using unique customized measures and / or one or two of a range of different standardized measures that rarely capture broader aspects of fatigue. Few studies assess the different dimensions of experiential fatigue.
- Understanding would be improved if applied studies were to use a standard measure battery that captures (i) acute and generalised sleepiness; (ii) acute and generalised broader fatigue; and (iii) various dimensions of experiential fatigue. The battery should include instructions on when fatigue and sleepiness should be measured in operators, in relation to their work. Candidate measures for such a battery are:
    - Generalised sleepiness: Epworth Sleepiness Scale (Johns, 1991)
    - Generalised fatigue in several dimensions: Swedish Occupational Fatigue Index (Åhsberg, 2000)
    - Acute sleepiness: Karolinska Sleepiness Scale (Åkerstedt, 1990)
    - Acute fatigue: Samn-Perelli scale (Samn and Perelli, 1982)
- Tables of average scores and shares of samples scoring above threshold scores on each constituent battery measure would improve understanding and help managers and regulators assess the severity of fatigue in different operator populations.
- Difficulties associated with the measurement of physiological aspects of fatigue might also be improved by standardization, together with a focus on naturalistic observations of operators in real world situations.
- There is a need for more research on the interrelated health and safety effects of accumulative fatigue.
- Authors should be explicit about their operationalization of fatigue, especially in relation to sleepiness.

We note the following about the assessment of the fatigued process:

- Working time and sleep quantity and quality have been relatively well studied in all sectors. Road studies are more concerned with charting work and sleep patterns in relation to general fatigue levels, while rail studies tend to focus on the acute effects of schedules on fatigue at work. Sea studies are characterized by a focus on the effect of watch systems on sleep and fatigue.
- There is increasing recognition that the quality of work may be just as important as the quantity of work (i.e. work time) in terms of resulting fatigue. Further understanding would be gained by studying explicitly the performance and health costs of having to maintain performance of a primary operator task when one is disengaged from the job. There is also a need to study how the psychosocial and physical quality of work interacts with working time to cause fatigue.

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- Comparative studies of the different conditions faced by operators in different subsectors, and the resulting effects on fatigue and performance, would help illustrate the fatigue-related challenges to regulators and organisations.
- The quality of life outside work has been overlooked as contributor to fatigue at work.

We draw the following conclusions about the assessment of the effect of fatigue on performance:

- Improved reporting of near misses and accidents in all sectors would help in the study of the role of fatigue.
- There is a need to standardize the periods for which operators are asked to report on incidents of severe sleep (or falling asleep) while operating.
- Increased observation of fatigue preceding incidents in naturalistic settings would assist understanding. Increased use of operational parameters, such as brake and accelerator use, could help chart the effects of fatigue on real performance.
- The way in which fatigue influences more complex aspects of performance (e.g. increased reliance on default mental schemas) has yet to be considered, but requires that such performance effects can be operationalized for study.
- There is a need for greater consideration of the costs of fatigue to the long term health of the operator and to performance of safety tasks that are secondary to the main operator task.

Accepting a broad treatment of fatigue, we have expanded Dawson and Fletcher's (2001) five-level fatigue-risk trajectory to account for fatigue determinants beyond working time, and recovery from fatigue beyond sleep. The modified trajectory helps us think about how to manage the risks related to broader fatigue. A consideration of the findings of the studies retrieved for this report in relation to the modified trajectory reveals the following:

- While work time has been well studied, there is a need to consider how work time, work quality and non-work life quality interact to influence operator fatigue.
- It has been established for many operators that restricted sleep and perceived fatigue results from work time demands, and that restricted sleep impedes recovery. However, there is much less consideration of recovery during non-work wake time, which evidence suggests is important. Such recovery could be assessed using a measure of need for recovery following work and preceding subsequent work periods (Sluiter et al., 2003).
- The fatigue assessment battery described above, supplemented by the identification of fatigued operator symptoms and behaviours, could help trigger countermeasures that prevent operator fatigue affecting performance.
- Considerations of main fatigue predictors based on sleep history, time on task and time of day are the basis of software parameters allowing schedulers to predict fatigue risks. However there is little understanding of the dynamic interactions between poor sleep and health and psychosocial pressures, which may lead to risks that are poorly predicted by existing software.
- Longitudinal studies on the effects of accumulative fatigue and burnout on operator performance and attrition from the industry are required.

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Appendix 1– Some notes about individual studies

Notes on road studies

	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
1	Survey attempting to link health, health behaviour, to risk for sleep apnea in Brazilian truck drivers (C. R. C. Moreno et al., 2004)	10,101 truck drivers	Survey of drivers stopped stopped at roadside campaign booths,	Demographics; health behaviours, sleep apnea risk (Berlin Questionnaire)	Made up question about tiredness during the day.	Blood samples taken to measure obesity and blood pressure indicators.
2	Postural control as a potential measure of sleep deprivation in Brazilian truck drivers (Albuquerque et al., 2011)	17 truck drivers	Drivers tested before and after shift, and asked to fill out Epworth Sleepiness Scale	Total sleep in last 24 h, wake time since last sleep, trip length.	Epworth Sleepiness Scale, postural control	
3	National US survey "Sleep in America 2012: Planes, trains, automobiles and sleep" (National Sleep Foundation, 2012)	203 truck drivers (ca. 1:2 long:short haul), 210 bus drivers	Web panel data collected by market research company	Length of average shift, schedule regularity, frequency schedule starts at night, average length of time between shifts, commuting time, second job, time at work each week, sleep habits, sleep sufficiency, sleep problems, napping, caffeine use	Epworth Sleepiness Scale	Sheehan disability scale, determines functional impairment in 4 domains: mood, family/home, social life and work. Drowsy driving not at work.
4	Fatigue and effects on performance in NZ truck drivers (Charlton & Baas, 2006)	606 truck drivers	Survey and psychomotor test protocol (20 minutes) given to drivers at truck stops, depots, ferry terminals. Number of different truck types stopped as to represent national data.	Demographics, experience, type of employment, vehicle and cargo type, average work day length, typical driving distance, "To what degree is fatigue perceived as hazard?". Activity survey to assess time spend driving, sleep periods, timing of meals, exercise, freight loading, desk work, rest periods, as well as partying or drinking in last 48 h	Epworth Sleepiness Scale Self-rated momentary fatigue measured using 7-point bipolar scale adapted from USAF crew status survey (Charlton, 1996) (1= fully alert, 3=somewhat fresh, 7=completely exhausted).	Psychomotor performance, commercially available Truck Operator Proficiency System (TOPS) testing software.
5	Sleep history, sleepiness and accidents in Swedish	1389 male drivers (161 subject to sleep study at home);	Mail survey	Demographics, occupational driving patterns and distances, sleep problems (waking, snoring,	Epworth Sleepiness Scale	Accidents in last 10 year (commuting, leisure or at work), health status.

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	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
	truck and bus drivers (Carter et al., 2003)	control group of 4000 men in other occupations		apnea), sleep habits, health habits, health status, sleep debt (how many h do you sleep? How many h do you want to sleep?) Home sleep study gave technical assessment of sleep apnea		
6	Stress and fatigue in Australian long-distance bus drivers. (Raggatt & Morrissey, 1997)	Ten long distance bus drivers on 12 h shifts (11 h driving with 1 h break)	Measures of stress and arousal collected in instrumented vehicle; Logbooks also filled out on work and rest days.	Time on task (with time at rest as control), health behaviour and dietary habits	HR;catecholamine levels; self-reported stress and state anxiety (State-Trait Anxiety Inventory and Stress/Arousal Adjective checklist, with 4-pt response scales from 1 = defintitely feel to 4 = definitely do not feel)	
7	Need for recovery in Dutch coach drivers (Judith K. Sluiter et al., 1999)	363 coach drivers from Dutch private sector	Survey sent to random sample of all coach drivers in Dutch private sector. 55 per cent response rate.	Details of personal life, work experience and aspects of work characteristics, working hours in high and off seasons and last working week. Job demands operationalised by number of hours per week. Job control operationalised as ability to control time, breaks, how long in advance schedule known. After Feyer et al. (1993), drivers asked for views and experience of driver fatigue, including its effects on driving; to what extent it is a problem for them personally; and for sector. Perceived Load Scale (Meijman, 1991); Sleep Quality Scale (Meijman, 1988)	After Feyer et al (1993), fatigue operationalised to include feelings of sleepiness, drowsiness, tired, being unable to concentrate, sustain attention or feeling mentally slowed down. Fatigue also tapped by Need for Recovery Scale (Van Vedlhoven and Meijman, 1994).	Psychomatic Complaints Scale (Dirken, 1967), emotional exhaustion tapped by part of the Maslach Burnout Inventory (Schaufeli and van Dierendonck, 1994).
8	Sleepiness in Finnish truck drivers (Häkkänen & Summala, 2000b)	217 truck drivers. (184 long- and 133 short-haul)	Survey completed voluntarily in terminal of large Finnish trucking company or during voluntary training event organised by union. Response rate here 10 per cent. B: questionnaires handed out at company's annual training day. Here 95 per cent response rate.	Basic Nordic Sleep Questionnaire, normal and maximum shift lengths (also coping with sleepiness).	Epworth Sleepiness Scale, sleepiness on job and frequency of dozing while driving in last 3 months, percentage of trips with problems staying alert.	Frequency of near misses on 3-pt scale from never to at least twice, in last 3 months.

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	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
9	Carrier scheduling and driver fatigue: a model (Crum & Morrow, 2002)	Executive directors, safety directors, dispatchers and drivers working for US motor carriers surveyed	Sample firms randomly selected from stratified SafeStat, US's compliation of safety performance-based variables for each known motor carrier. Safety Director called, and those consenting (66 per cent) sent a safety pack of seven surveys - one each for the executive and safety director, two for dispatchers and three for drivers. 31 per cent conseting to participate returned usable surveys.	Regularity of time, quality of rest, trip control, economic pressures, carrier support for driving safely, perceived frequency of others driving tired.	Frequency of driving "tired".	Number of close calls because of less-than-full alertness.
10	Multinational survey of fatigue in truck drivers (Adams-Guppy & Guppy, 2003)	640 drivers and 116 managers surveyed, working for a large multinational in Europe, America and Africa.	Surveys distributed through internal mail system. Average driver response 53 per cent, manager response 27 per cent.	Demographics, current driving, work features, shift end-start times and patterns, driver behaviour and perceptions about break taking, work satisfaction and involvement with route planning and scheduling, health behaviours.	Reported frequency of fatigue problems (how often do you drive tired, how often do you find concentration lapsing).	Accidents and near misses in last three months.
11	Fatigue in truck drivers at Israeli ports (Sabbagh-Ehrlich et al., 2005)	160 port truck drivers agreed to interview.	Field interviews at port, based on survey comprised of 80 closed-ended (multiple choice) items. Driver response rate 25 per cent.	Driver charactersitics, workplace and driving conditions, employer-employee relations, medical conditions, sleep quality (Pittsburgh Sleep Quality Questionnaire).	Fatigue (experienced fatigue while driving - does not appear to define period)	Falling asleep at the wheel, involvement in road crashes.
12	Effect of work practices on fatigue in Australian long distance truck drivers (A. M. Williamson et al., 1996)	27 Australian truck drivers from two companies completing a 12 h trip on each of three driving regimes: relay or one-way single trip with (must break for 30 min after 5 h driving) or without working time regulations	Within subjects experiment with on board data logging, offroad cognitive testing at start, middle and end of trips, and trip diary. Additional survey for background information.	Work and non-work activities and break times. Work and rest during week prior to study.	On-road heart rate variation, subjective fatigue at beginning and end of each trip, and at beginning of each break using Stanford Sleepiness Scaleand three bipolar visual analog scales (fresh-tired, clear headed-muzzy headed, very alert-very drowsy).	Cognitive tests of perceptual sensitivity, reaction time, vigilance task and tracking task. Speed and steering variability during trip, health status (from survey)

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	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
13	Survey of NZ truck driver fatigue and fitness for duty (Baas et al., 2000)	600 truck drivers	Interviews, survey and simulator performance tests (total time 2 h) conducted at depots, wharves, markets and other locations in NZ.	Survey: hours driven and amount of sleep in past 48 h. Interview: driver demographics, work/rest patterns, driver attitudes to fatigue, propensity towards daytime sleepiness.	Made up question on momentary level of fatigue included in short survey; also Epworth Sleepiness Scale	Asked in survey how sleepiness affected them. Simulator-based performance test (10 min) of driving (TOPS), measuring divided attention, steering, vehicle heading, curvature error, throttle activity, acceleration and speed.
14	Factors linked to US truck drivers' sleep at the wheel (McCartt et al., 2000)	192 long-haul drivers	Random selection of drivers for interview, at rest areas and roadside inspections. Drivers offered 5 dollar food voucher. Response rate 35 per cent.	Demographics, work and rest patterns, symptoms of sleep disorder, measures of driving exposure.	Epworth Sleepiness Scale	Incidents of sleep at the wheel.
15	Before-after driving measurements on bus drivers and survey of truck drivers in former Yugoslavia (Milosevic, 1997)	58 bus drivers; 200 long-haul truck drivers and 107 dump truck drivers.	Bus: biochemical, cognitive and psychophysiological tests before and after 7 h driving. Truck/dump: questionnaire on activities.	Before and after driving	City bus test battery: biochemical markers (adrenaline etc), physiological markers (ear temperature, blood pressure), vision (accommodation, convergence), psychological (visual and auditory reaction time and subjective evaluation of fatigue (oft-used; by Pearson and Byars) from 0 = very tired to 20 = very fresh). All taken before and after driving.	
16	Sleepiness, health heavy vehicle drivers in Finland (Häkkänen & Summala, 2000a)	567 heavy vehicle drivers (44 per cent long-, 25 per cent short-haul, 7 per cent bus, remainder other truck).	Members of truck driver interest group selected at random, and sent questionnaire with stamped return. Response rate 34 per cent.	Demographics, driving experience, preceding 3 months' work (average driving time per shift, type of shift, cargo type), whether governed by driving regulation, health behaviours. The Basic Nordic Sleep Questionnaire was used to collect data on sleep apnea, sleep history and sleepiness.	Epworth Sleepiness Scale, sleepiness at wheel, sleepiness-related problems at work (e.g. percentage of trips with problems staying alert) for preceding 3 months.	Health status (4 pt scale form poor to good). Using a 7 pt scale from never to over 21 times, the frequency of dozing off while driving and following near miss situations was asked about.
17	Work and rest in long-haul drivers in Australia (A.-M. Feyer & A. M. Williamson,	n=989 long-distance truck drivers.	687 completed a questionnaire, distributed through the companies or at company depots, truck stops	Information on work, rest and fatigue, type of employment and working conditions, details of work and rest on last trip in working	Fatigue appears to be assessed by a single item rating.	

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	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
	1995b; A. Williamson et al., 1992)		and freight distribution centres. 302 interviewed at truck stops. Drivers could choose between survey or interview at truck stops. Survey resposne rates quite low (15-20 per cent), but refusal rate for interviews low.	week, and drivers' views on and experience of fatigue. See 2001 study		
18	Follow-up national survey of long-haul drivers in Australia (A. Williamson et al., 2003)	n=1007 long haul drivers	Ca. 50:50 self-administered survey and research interview (results combined). Sampled at truck stops, stratified according to an analysis of the Australian road transport industry.	Demographics, employee or owner-driver, no. of trucks in company, business type, years driving, place of home base, main types of freight, payment type, vehicle type, weekly work/rest schedule, change in awareness of fatigue (for industry and you personally), hours into trip when fatigue begins, times most fatigued when working (shade in hour chart), how fatigue affects driving, causes of fatigue, strategies, how well fatigue managed by industry, by you, what company/government does or should do about fatigue. Details of last trip: place started, when started, time starting work, time starting driving, place trip finished etc.	"How often fatigued while driving?" "Fatigue a problem for you vs industry?" Epworth Sleepiness Scale.	Survey also contained sections on fatigue related dangers, and breaking the rules.
19	Survey and field study of US truck and bus drivers (Mackie & Miller, 1978)	500 owner-operators, private carrier drivers and charter bus drivers on irregular schedules completed survey; over 3000 driver logs inspected. 12 truck and 6 bus drivers participated in 6-day field study, driving regular (day) and irregular (all times	Recruitment at truck stops near cities, loading docks and trucking or bus company depots and terminals. Response rate not clear.	Survey: employment type, driving patterns, operation type (sleeper, relay, city/local), duty cycles, mileage for preceding 6 days, sleeping conditions and location. Field study: schedule type (regular daily schedule from 0600 to 2000 compared with irregular schedule); diet and activity also recorded.	Throughout trip regular subjective ratings of fatigue on 7-point scale from "I have never felt more rested" to "I have never felt more tired"; also on 11-point scale for alertness, and Stanford Sleepiness Scalefor sleepiness. Heart rate, body temperature, EEG and adrenaline / noradrenaline levels also recorded.	Steering reversals, lane tracking, speed (primary performance), and performance on secondary tracking task recorded in seat when stopped.

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	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
		of day and night) schedules.				
20	Effect of truck type on driver fatigue and stress in US (Battelle Human Factors, 1996)	24 experienced longer-combination truck drivers	Controlled experiment, repeated measures: do longer-combination trucks induce more driver fatigue and stress than single trucks? Instrumented vehicle monitored performance on a 4300 km drive over 7 d, where the driver used alternately 2 LCV types (A and C dolly) and a single trailer vehicle. Driver answered survey and was tested at 5 scheduled times during the drive.	Survey: NASA TLX (task load). Physiological: Heart period (physical and mental workload).	Stanford SleepinessScale, Worksafe Australia Questionnaire (perceived change in fatigue level).	On board instrumentation: lane deviation, steering wheel corrections. Computer probe tests: critical tracking task (hand-eye coordination), unprepared simple reaction time, two finger tapping test (motor coordination), code substition task (perception and short-term memory)
21	Sleep, alertness and fatigue in city bus drivers (Diez et al., 2011)	47 Brazilian city bus drivers	Actigraphy and sleep logs, cognitive and psyhophysiological testing and salivary sampling.	Morning /afternoon versus afternoon/evening shifts, sleep quality (Pittsburgh sleep quality index), cortisol from saliva, objective (actigraphy) and subjective (logs) sleep quantity/quality.	Epworth Sleepiness Scale (Spanish version), EEG (electrodes attached 30 min before shift start), heart rate variability and alertness tested at 0, 4 and 8 h after shift start.	PVT test
22	Sleeping, driving, and health characteristics of Belgian truck drivers (Braeckman et al., 2011)	476 Belgian truck drivers	Cross-sectional data collected using a self-administered questionnaire of random sample, with 30 per cent response rate.	Sleep quality measured with Pittsburgh Sleep Quality Index and sleep problems with Berlin Questionnaire	Sleepiness measured with Pittsburgh Sleep Quality Index, Epworth Sleepiness Scale	
23	Field study of sleep and fatigue in Australian truck drivers working rotating 12 h shifts (Stuart D. Baulk & Adam Fletcher, 2012)	20 truck drivers working 2-days, 2 nights then 4 off.	Data from actrigraphs, sleep/wake diaries and PVT collected over 14 d period	Sleep and nap start-end times, number of awakenings during the sleep period. Objective sleep quantity/quality (actigraph)	Subjective fatigue on 7-pt scale (Samn & Perelli, 1982) taken at start and end of shift	5 min PVT (Dinges & Powell, 1985) to measure reaction time. Taken at start, midpoint and end of shift
24	Fatigue and sleepiness in bus drivers in Japan who work shifts (Asaoka et al., 2010)	2403 bus drivers working 3 types of shift	Surveys, actigraphs and tests.	Shift type, blood pressure, BODY-MASS INDEX.	Epworth Sleepiness Scale	Shiftwork disorder

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	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
25	Fatigue in bus drivers in Kuwait: occurrence and driver nationality effects (Alrukaibi & Koushki, 2008)	486 bus drivers working long hours	Drivers in interview-survey conducted at bus terminal	Socio-economic conditions of driver (5 items)	Awareness of fatigue (12 items, written for this survey)	personal experience of driving with fatigue (10 items)
26	sleep and sleepiness in Brazilian long-haul bus drivers working shifts (Santos et al., 2004)	32 drivers on a randomly selected interstate route	Polysomnography tests in lab performed at bedtime following night or day shift. At end of recordings, mlst.	Shift time (night, 2230-0630, or day, 0930-1730)	MLST, polysomnography	
	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
27	Sleep patterns and sleep-related complaints of Brazilian interstate bus drivers (Mello et al., 2000)	400 drivers	Interviewed at driver depots and/or bus stations when drivers off-duty, with sleep questionnaire used in previous Brazilian studies (96 items).	Sleep patterns, sleep-related complaints, physical activity, social class, educational level, weekly work schedule, marital and family status, health behaviours.	Indexed by anxiety and depression: State-trait Anxiety Inventory, Beck depression inventory.	
28	Naturalistic study of fatigue in local/short-haul truck drivers in US (R.J. Hanowski et al., 2011)	42 drivers in US, from 2 companies, one hauling beverages, the other snack foods.	Drive one of two instrumented trucks for two weeks. Also objective (PERCLOS, actigraph) measures taken. Drivers also completed questionnaires before and after sleeping, and before and after shifts. Participating drivers were paid. Most drove Mon-Fri.	Sleep quantity and quality (objective, subjective), activities.	PERCLOS and OBSERV (observer ratings of driver drowsiness on scale from 1 (not drowsy) to 100 (extremely drowsy), prior to a critical incident for which driver at-fault.	Critical incidents occurring while driving
29	Dimensions of fatigue in city bus drivers in Sweden (Elizabeth Åhsberg, 2000)	148 bus drivers	Answer questionnaire after driving a bus in Stockholm for a morning or afternoon (not night) shift	Workload tapped by questions on demands (do you have too much to do, are your work tasks too difficult) and control (can you regulate the work pace, can you decide how to perform the work), responding on a 5-pt scale from "not at all, or short moments" to "all or almost all work time".	SOFI - participants rate 25 verbal experessions from 0 = "not at all" to 6 = "to a very high degree"; Borg CR10 used as a measure of general fatigue.	
30	Effect of pay systems and waiting in Australian long haul trucking on driver experiences	475 truck drivers	Drivers interviewed or fill out surveys at rest stops along a major transport route, between	Demographics, perceived work-life balance, driving experience, working arrangements (vehicle type,	Fatigue experiences: on last trip ("how did you feel when you	Safety outcomes ("have you had a crash driving a heavy

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	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
	of fatigue (Ann Williamson & Friswell, 2013)		0600 h and 0200 h. Two-thirds opted for self-report against interview. Response rate 30 per cent overall.	employment type, payment system, usual weekly hours, payment for non-driving work), details of last round trip (distance, freight carried, fatigue management system, pay, pre-trip rest, trip hours, deadlines, participation in and payment for queueing, loading and local driving).	started?", "did you get fatigued at any stage?"), fatigue on trips generally.	truck for work in the last 12 months?")
31	Driver alertness and fatigue in US and Canada (Wylie, Schultz, Miller, Mitler, et al., 1996)	80 drivers of various heavy vehicle types on 4 different driving schedules.		Daily log, health, food and sleep habits. Pretrip questionnaire on sleep habits. Polysomnography during sleep.	Stanford Sleepiness Scaleratings, EG/EOG/EMG, respiratory air flow, body temperature	Driving performance measures during driving (tracking, steering, on-face + road video) and off-duty PVT TEST
32	Impaired vigilance and accident rate in bus and tram drivers in Sweden. (Karimi et al., 2013)	87 (ca.50:50 bus and tram) transit operators in Gothenburg.	Overnight polysomnography during sleep and questionnaire data to identify those with sleep disorders.	Baseline measures of habitual subjective total sleep time, sleep quality, sleep latency (time to fall asleep), sleep duration and sleep sufficiency (well-rested, rested, not rested). EEG, EMG and EOG recorded in sleep (to diagnose OSA episodes). Insomnia Severity Index.	Karolinska Sleepiness Scale, Epworth Sleepiness Scale	Fatigue symptoms in cognitive, physical, and psychosocial domains were assessed using the Swedish version of the Functional Impact of Sleeiness scale, International Restless Legs Syndrome Scale. Health impacts assessed using SF36. Previous motor vehicle accidents in past 1 or 5 y.
33	Naturalistic study of effect of driving and non-driving work on safety of US truck drivers (Soccolich et al., 2013).	n=97 line-haul drivers, driving 735,000 miles altogether.	Analysis of data collected for US Naturalistic Driving Study	Driver log to record periods of work and non-work, and type of non-work activity i.e. eating, sleeping, resting, loading, light work etc.	Systematic observations of video footage while driving for driver fatigued state (OBSERV)	
34	Fatigue in light/short haul drivers in Australia (R. Friswell & Williamson, 2008) (R. Friswell et al., 2006)	321 drivers from range of companies, for which transport main or auxillary function, e.g. producers of building materials, food and beverages.	Companies in New South Wales likely to be involved in light(short-haul transport (<100 km, < 4.5 t GVM) identified from commercial telephone listings. 70 per cent of eligible companies willing to take part, but only 318 surveys returned of 3899 sent out. Same happened during trial at truck stops: interest in survey, but not	Survey based on that in (A. Williamson et al., 1992) and (A Williamson et al., 2001). Demographics, drivers' work, size and primary business of company, veichle driven, distances travelled, cargo tasks, amount and timing of work, work tasks, external constraints on timing and predictability of work, commuting time, NASA Task Load Index, visual analog scale of	Epworth Sleepiness Scale, Need for Recovery Scale(E.M. De Croon, Sluiter, & Frings-Dresen, 2003)	Self-reported effects of fatigue on driving

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	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
			many returns. Ultimate overall response, 8.1 per cent.	workload, fatigue experience (frequency, time of onset, effect) and attitude (self and industry), sleep disturbance and sleep apnea risk. Work, sleep and fatigue over an actual working day.		
35	Sleep and sleepiness at work in Norwegian drivers (part of Hordaland Health Study) (Ursin et al., 2009)	231 professional drivers of all types of land-based vehicles (including mobile plant operators). Other occupations and leaders also surveyed.	Self-report survey administered by health screening service.	Shift work, h of work per week, and from Karolinska Sleep questionnaire: work week bed- and rise-time, free time bed- and rise-time, sleep latency on work week nights and free time nights, subjective sleep need, tiredness or sleepiness at work or durin g free time, insufficient sleep and falling asleep at work, circadian type, subjective health, sedentary or manual work, education, family status, exercise, urban or rural.	Tiredness or sleepiness during work or free time	
36	Sleepiness and sleep disorders in commercial vehicle drivers in Australia Howard et al (2004)	2342 commercial vehicle drivers responding to survey, 161 subject to polysomnography during sleep.	Random sample of 98 workplaces selected from 395 workplaces on the database of the Transport Workers Union in Australia. Workplaces visited by study investigators and questionnaires distributed to drivers. Survey response rate 72 per cent. 244 drivers selected for polysomnography, of which 161 accepted.	Demographics, sleep habits, work habits, Multivariable Apnea Prediction questionnaire used to assess probablility of having sleep-disordered breathing.	Epworth Sleepiness Scale (11 or more indicated excessive sleepiness).	Functional Outcomes of Sleep Questionnaire included to measure sleep related to quality of life. Self-reported accidents from last 3 years.
37	Long hours and fatigue in US tractor-trailer drivers (Braver et al., 1992)	Survey of 1249 tractor-trailer drivers	Trained researcher interviews at truck stops and truck inspection stations.	Hours of work, attitudes to and knowledge oh hours of service violations, payment methods, pay rates, late arrival penalties, fleet size, trip, weekly, annual mileage, days per trip, cargo (perishable?), owner-driver.	Incidences of sleep at wheel.	

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	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
38	Study of night drive in Swedish truck drivers (L. Kecklund et al., 2001)	18 truck drivers on night (20:30 to 07:20) or evening (18:20 and 0400) drive	EEG recorded continuously during a 500km night or evening drive. They also carried out self ratings of sleepiness and performance every hour.	EEG, Karolinska Sleepiness Scale.		
39	Fatigue in taxi drivers in Sydney, Australia (Dalziel & Job, 1997)	42 city taxi drivers	Detailed questionnaire developed in consultation with industry. Drivers informed of study via messages on computerized job dispatch service and information posters at central gas stations. Surveys distributed at gas stations and local taxi ranks, central boxes provided for return.	Age, time with taxi licence, Type of shifts, number and length of shifts and breaks, employment type, job-related and attitudinal variables where driver asked to rate driving abilities of selfin relation to average other taxi drivers.		Falling asleep at the wheel. Accidents in preceding 2 y.

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Notes on rail studies

	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
1	National sample survey of US transport workers including train operators (National Sleep Foundation, 2012)	180 train operators (conductors/ train operators in cargo and passenger transport), and control group of 292 non-transport professionals.	Web panel data collected by market research company	Length of average shift, schedule regularity, number of times schedule starts at night, average length of time between shifts, commuting time, second job, h at work each week, sleep habits, sleep problems, sleep sufficiency, napping, caffeine use	Epworth Sleepiness Scale	Sheehan disability scale, determines sleep impact on mood, family/home, social life and work. Drowsy driving not at work. Sleepiness impact on job. Near misses at work due to sleepiness.
2	Looking at factors other than working time on sleep quantity and quality in rail safety workers in Australia (Paterson et al., 2012)	40 safety workers working for cargo transport; 23 locomotive drivers, and 17 other.	Recruitment sessions and posters put up in companies, asking for participation. Consenting participants sent pack in post: survey, sleep and work diaries, actigraph. Participannts asked to fill in diaries and wear actigraph over 2-week period.	Demographics, including commuting time, caffeine use, health status, domestic status, partner's employment status, BODY-MASS INDEX. Sleep diary: start-end times and location of sleeps and naps, sleep quality. Work diary: start/end work period, nature of work.	Pre- and post-sleep and pre- and post-work period fatigue levels collected in sleep and work diaries using in both cases the Samn-Perelli fatigue scale (1= fully alert, wide awake, 7= completely exhausted unable to function) (Samn & Perelli, 1982)	
3	Effect of irregular shift system on train operator and rail traffic controller sleepiness in Finland (Härmä et al., 2002)	126 male train operators and 104 male traffic controllers, randomly selected from national register	Questionnaires and sleep diaries, issued to participants on visit to sleep laboratory; return visit to laboratory after 21 d. Diraries completed every day for 21 d, inc. Karolinska Sleepiness Scale. Any nodding off also recorded. MWT and cognitive performance tests carried out day after study period.	Schedule factors (start-end shift times) and sleep length, lights-on and -off times, sleep latency, coffee, alcohol, medicine use, training courses, demographics, BODY-MASS INDEX, experience, dependents (children under 7)	Karolinska Sleepiness Scale completed at start and end of each shift, and whenever particpant felt sleepy. Objective wakefulness test post study. Post-study shiftwork questionnaire about frequency of sleepiness at work in connection with morning, evening and night shift.	Sick leave, post-study cognitive performance.
4	Work/rest schedules of US train and engine service personnel in passenger service (J. Gertler & DiFiore, 2010)	Random train operators (drivers and conductors on passenger trains) in three groups, as identified from union lists: straight thru shift, split shift and those on-call	Background mail-survey; daily log completed for 2 weeks. Schedules analysed using software "Fatigue Avoidance Scheduling tool (FAST)" for high fatigue risk. FAST is based on the Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) model to predict effectiveness (lack of fatigue) at work.	Mail survey: demographics, job nature; sources of stress at work, fatigue training, work schedule; health status, caffeine use. Log: daily sleep activity, sleep disturbances, sleep quality, personal time, commute time, break time, work time, limbo time.	Level of alertness at start and end of each work period. Background survey also asked about alertness at work.	Sickness absence, health status

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	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
5	Work schedules and sleep patterns of all train and engine service employees (J. Gertler & DiFiore, 2009)	Random sample of 809 rail employees, 89 per cent of which were either drivers (49 per cent) or conductors (40 per cent).	As above, i.e. mail survey, logs and FAST analysis. Response rate 33 per cent	As above.	As above	As above
6	Reanalysis and comparison of five survey studies on US railroad done from 2006-11, 2 of which are those immediately above, with respect to work schedules and sleep (Raslear et al., 2013)	Safety-sensitive positions on rail i.e. track maintenance, signalmen, dispatchers, train and engine employees (mostly drivers, conductors)	Schedule type	Fatigue exposure / risk calculated from schedule analysis using FAST		
7	Effect of naps on sleep and restedness in irregular work schedules (J.J. Pilcher et al., 2005)	179 freight train operators	14-day log	Napping, sleep length, self-reports on ability to go to sleep, ability to stay asleep	Restedness on waking	
8	Effects of organisational factors and scheduling on fatigue, health and wellbeing in US freight crews (Ku & Smith, 2010)	125 train operators and conductors.	Response rate 46 per cent	Organisational factors: organisational support, autonomy, job control, interpersonal relationships, interpersonal conflict, job satisfaction, working environment. Scheduling factors: length of working hours, variety, predictability, discipline and rest window. Sleep Quality adapted from Standard Shiftwork Index by Barton et al. (1995).	Fatigue: Fatigue-Inertia, Vigor-Activity and Anxiety. Latter from POMS mood status. Anxiety scale from NIOSH health checklist (Smith et al. 1981).	Health problems, Social wellbeing
9	Behaviour and subjective fatigue train operators in France (Gouin et al., 2001)	6 train operators	Video recording in cab of driver's face and eyes on trips lasting 2, 4 or 6 h; also survey	Eye movements. Survey measured physical symptoms (headache, backache etc.), psychological aspects (anxiety, irritability), communication and social aspects, sleep quality and health-related aspects	Fatigue (Neville et al. 1994): agreement with "I'm somewhat fresh", "a little tired", "moderately let down" etc.	Eye movements.

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	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
10	Train operator sleepiness on early morning shifts in Sweden (Ingre et al., 2004)	17 experienced train operators	Within groups study. 17 drivers drive 4.5 h trip in two directions, with 2.5 h break in between, on early shift (ca. 0600), day shift and evening shift. Retrospective Karolinska Sleepiness Scale ratings at each stop. Sleep diary filled out on morning before each drive.	Diary: sleep times prior night, rating of stress at bedtime, ease of falling asleep, disturbed sleep, sleep quality, difficulty awakening, insufficient sleep, caffeine intake.	Karolinska Sleepiness Scale completed at each stop (10 stops in 4.5 h trip)	
11	The effect of subsequent shift start time on sleep length in train operators in Sweden(Ingre et al., 2008)	46 train operators driving long distance (4-5 h trips) or local trains.	Diary study for 14 days, supplemented by survey	Sleep, stress, sleepiness and working hours from diary. Demographics, health and wellbeing from survey.	Karolinska Sleepiness Scale, but results nor reported.	
11	Fatigue and sleepiness in train operators working shifts in Japan (Asaoka et al., 2010)	706 train operators working morning til evening shift or 12:00 one day to 12:00 the next with 5 h rest at night.	Surveys, actigraphs and tests.	Objective sleep, shift type, blood pressure, BODY-MASS INDEX, obstructive sleep apnea syndrome (OSAS) ,	Excessive daytime sleepiness (Epworth Sleepiness Scale?)	Shiftwork disorder (SWD)
12	Dimensions of fatigue in train operators in Sweden (Elizabeth Åhsberg, 2000)	143 train operators	Drivers asked to rate fatigue using the Swedish Occupational Fatigue Inventory, after a night conveying goods.	Workload tapped by two questions on demands (Do you have too much to do? Are your work tasks too difficult?) and two on control (Can you regulate the work pace? Can you decide how to perform the work?), responding on a 5-pt scale from "not at all, or short moments" to "all or almost all work time".	SOFI - participants rate 25 verbal experessions from 0 = "not at all" to 6 = "to a very high degree"; Borg CR10 also completed to give a comparative score for general fatigue.	
13	Effect of work history performance of train operators in Australia (Dorrian et al., 2007).	50 cargo train operators (shipping containers) from two deptots	Drivers assigned by experimenters into 3 groups, depending on FAID ratings of work history: low fatigue, medium or high. Drivers drove in pairs, swapping driving every 2 h and working the same schedule. Researchers did not know which driver was driving at any one time.	Work history (i.e. whether schedule rated as giving low, medium or high fatigue)		Fuel use, fuel consumption, braking, speed. (The railway operator intermittently downloads data for trains to monitor handling for QC and training purposes.)

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	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
14	4 part study of fatigue in French train operators: i. schedule analysis for fatigue risk, ii. analysis of how well reporting systems allow companies to manage fatigue, iii. Survey of driver's fatigue perceptions, iv. Field data collection. Latter two covered here. (Cabon et al., 2012)	1295 train operators	Survey sent to personal addresses and returned directly to research laboratory for data processing, response rate 37 per cent. Field study: actigraphy and sleep log covering days at work and days off before and after a working period; fatigue assessed during trips by EEG and EOG and Karolinska Sleepiness Scale. Sleep Wake Predictor used to predict Karolinska Sleepiness Scale sleepiness and compared with actual values.	Survey: perceptions and attitude about schedule, working hours, sleep and sleep conditions. Field study: subjective and objective sleep duration and quality	During trips: Karolinska Sleepiness Scale (actual), Karolinska Sleepiness Scale (predicted), EEG, EOG.	
15	Effect of shift starting time on subjective fatigue in train operators in Australia (Paech et al., 2011)	38 train operators working 7 forward-rotating day shifts then 7 forward-rotating night shifts in rural mine	Participants asked to self-report on fatigue at start and end of every shift.		Samn-Perelli Fatigue Checklist	
16	Survey and diary study of shift patterns and implications for UK freight drivers - follow up of study on passenger drivers (Robertson et al., 2010)	312 surveys and 102 diaries returned from freight drivers.	Company visits and focus groups lay groundwork for study. Questionnaire (closed, multiple choice) and diary sent to drivers. Participants asked to fill in diary for 28 duty days. 3000 packs sent out, so response rate for survey (10.4 per cent) and diary (3.4 per cent) low.	Survey: Hours and shifts worked and rostering practices, travel time to and from work, gap between booking on and duty start, length of shifts, number of consecutive shifts, length of sleep between shifts, attitudes to shifts, breaks, overtime, swapping shifts, awareness of effects of shift work on fatigue, health, circadian, coping strategies, job satisfaction and wellbeing. Diary: Sleep prior to duty page (timing, quality and duration of sleep before a shift, naps prior to shift) and duty page (shift timing, recovery from last duty or duties, amount of driving, breaks within shift, naps.	Fatigue at start and end shift filled out in diary, based on Samn-Perelli scale. Recovery from last duty or duties mistakes on shift,	
17	Shift patterns and implications for drivers	460 drivers from various train operating companies complete	Survey, and diaries completed daily for 28-day period.	Survey: Shift patterns, length and timing of duty periods, breaks, rest periods,	Fatigue at start and end shift filled out in diary, based on Samn-Perelli scale.	

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	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
	of UK passenger trains (McGuffog et al., 2004)	survey, response rate 20 per cent. Diaries sent to 1635 drivers, with only 6 per cent returned.		recovery periods, patterns of shift rotation, swapping, and likelihood of errors on different shifts. Also questions on impact of shifts, social and environmental factors on health and wellbeing. Diaries: see above		
18	Prevalence of sleep apnea in UK train operators {Hack, 2005 #2396}	508 surveys completed by drivers for three train operating companies.	Railway specific sleep questionnaire sent out. Response rate 21 per cent	Items on BODY-MASS INDEX, sleep problems.	Karolinska Sleepiness Scale, Epworth Sleepiness Scale	
19	Work hours, workload, sleep and fatigue in Australian Rail Industry employees (Dorrian et al., 2011)	31 drivers and 59 other rail roles from four Australian Rail companies, driving freight or passenger trains. Data obtained for a total of 713 shifts with sufficient sleep history (48 h) for subsequent analysis	Participants carried out normal rosters and duties for a 14 d period. Managers allowed participants time to complete tests with researchers, when necessary. Participants completed work diaries, sleep diaries and wore actigraphs. Based on past research, having less than 5 h in 24 h prior to starting work, less than 12 h in 48 h prior to starting work (Dawson & McCulloch, 2005), working for 10 or more hours in single shift (Folkard & Tucker, 2003), being awake for 16 or more hours (van Dongen, Maislin, & Mullington, 2003), and samn-Perelli 6 or 7 (Samn & Perelli, 1982) used for threshold of increased likelihood of fatigue.	Work diaries: work start-end times, break time and duration, nature of work carried out. Sleep diaries: for each sleep (inc. naps), onset-wake times, number and length of wakenings in sleep period, rate quality from 1 = very good to 6 = did not sleep. Objective sleep quantity and quality (actigraph). Measures extracted from activity monitors and diaries converted to sleep in 24 h and 48 h prior to shift start and total wakefulness at shift end. Workload evaluated using NASA Task Load Index and mid- and end-point of each shift. NB TLX comprises 6 subscales: mental demand, physical demand, time constraints, performance, effort required, frustration. Each ppt asked to evaluate contribution of each dimension to the workload of their job roles, thus accounting for differences in individual perceptions.	Work diary: Samn-Perelli ratings before and after each shift.	
20	Effect of irregular shift systems on sleep-wake periods and the knock-on effects for alertness in US train	179 US train operators	Participants informed by managers to complete the 14 day activity log, the Train operator's activity Diary (Pollard, 1996)	Work times, sleep habits informed analysis by short (<22 h), normal (22-26 h) or long (>26 h) sleep-wake periods. Log also records time employer calls with duty times, commuting time, time not at work, in and out of bed times, ability to	Log records subjective on-duty alertness	

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	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
	operators (J.J. Pilcher et al., 2004)			stay asleep, restedness on waking, ability to go to sleep. NB originally logs spanned from midnight to midnight, but sleep-wake period much more practical.		
21	Moderators of effect of long work hours on health in UK train operators (Tucker & Rutherford, 2005)	372 train operators on short to medium distance routes, passenger services, from three train operators	1909 surveys sent out to union members by post to their home address, with prepaid envelope for return; cover letter from union secretary and researchers; reminder; 517 responses (27 per cent). 145 excluded if they were women or worked nights more than once a week (because this leads to poor health outcomes!).	Weekly hours, reasons for overtime (e.g. to cope with overload, because I enjoy my job, because I am told to etc), control over work hours, social support (colleagues, managers, friends, family). Demographics as control variables.	Chronic fatigue measured with Standard Shiftwork Index, which measures general persistent tiredness and lack of energy that persists on rest days and holidays.	Physical health symptoms (Standard shiftwork index with scales for digestive problems, heart disease symptoms, musculoskeletal pain), psychological health (GHQ12).
22	Effect of relay operations on train operator fatigue in Australia (S.M. Jay et al., 2005)	7 drivers working 5 d out and 5 d back trips in relay teams 8 on/ 8 off	Day before trip, baseline PalmPVT (Thorne et al., 2005) and fatigue ratings collected, then during and for 3 d after tip.		Samn-Perelli fatigue ratings before and after each shift	PalmPVT before and after each shift
23	Impact of shift work on train operators in Brazil, according to whether they are morning- intermediate or evening-types (de Araújo Fernandes Jr et al., 2013)	91 train operators working rortating shifts, including night shift.	Drivers asked to fill out survey, wear actigraph and carry out PVT before and after night shift for 10 d period. Results analysed after dividing them into 3 groups according to circadian type (Morningness-Eveningness Questionnaire).	Circadian type, objective sleep quantity and quality (actigraphy)	Subjective fatigue before and after shift, assessed by a visual analog scale where 0 represents no fatigue and 10 represents maximum feeling of tiredness	PVT before and after night shift

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Notes on sea studies

	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
1	Cardiff Sea Study Phase I (A. Smith et al., 2006)(Smith, Lane, & Bloor, 2001)	Ca. 500 seafarers in offshore oil support vessels, mostly UK registered.	Surveys, on board logbooks. Survey response rate 27 per cent (through union); 7-29 per cent (if distributed on vessel)	Demographics, sleep quantity/quality, nature of work, shift schedules, tour length, port frequency/turnaround, working hours per week, home-work interface, variable working hours, knowledge of fatigue, job demands, job support, job control, job security, perception of risk to personal safety, multitasking on watch, work off-watch, health and dietary habits.	Fatigue (fatigue subscale of the profile of fatigue related symptoms Ray et al., 1992). Custom measures of fatigue at work, fatigue after work.	Sense of well-being at work, and on leaving work, stress (mental health), physical health, fatigue-related incidents, collisions at sea (with other vessels or objects), sleep while on watch.
2	Cardiff Sea Study Phase II (Smith et al., 2003)	936 survey resposnes and ca. 150 assessments on board seven UK "short sea" ferry/cargo/tanker.	Surveys sent to seafarers as union members or company employees; combined response rate 21 per cent. Surveys also distributed by visiting researchers on board vessels, to supplement assessments using logbooks/diaries, actigraphs and psychomotor tests.	As above. Also on board testing of vessel motion, noise, and performance and mood using computerised visual analog scales for alertness, hedonic tone and anxiety; sleep measured objectively using actiwatch.	As above. Also simple visual analog scale assessment of subjective alertness on board.	Reaction-time task; focused attention task and categoric search task; salivary cortisol levels; fatigue-related incidents, health outcomes.
3	Cardiff Sea Study III (A. Smith et al., 2006)	350 survey responses from UK "deep sea", mini-bulkers, short-haul bulkers, containerships, reefers, tankers, cruise and fishing vessels.	Surveys sent to seafarers as union members or company employees; Response rate 11 per cent. Logbooks also completed "at sea" and "on leave".	Survey as for Phase I. Logbooks filled in for 28-35 d to record sleep start-end times, sleep quality, ship operations since their last main sleep period, time spent working, and fatigue experiences. Sleep and fatigue data collected both on board and on leave.	Largely as for Phase I	Largely as for Phase I
4	Fatigue at Sea - A field study in Swedish Shipping. (Lützhöft et al., 2007)	30 seafarers participate in field studies on board 13 cargo vessels over 3-5 d.	Survey, extensive sleep diaries completed on board and on leave. On board measurements using actigraphs, EOG (5 electrodes round eyes to measure eye movement) and performance tests.	Watch system recorded (6/6 vs. 4/8), sleep quantity / quality measured subjectively (diaries filled in before and after each sleep) and objectively (actigraph). Work start and end times also recorded.	Subjective: Karolinska Sleepiness Scale and corresponding stress scale taken every hour awake; Objective: EOG	Palm-top reaction time tests following day and night watches. General health surveyed (21 items).
5	Sleep disturbances and sleep-related safety problems on vessels of a Norwegian	577 offshore fleet workers on vessels operating in North Sea, Australia, South	Survey given out on vessels as they visited company headquarters in Norway, UK and Australia.	Watch system (6/6 vs 12/12) and single-item measures of sleep problems and contributors. ("How often do you suffer from	Implied from level of sleep disturbances	Single-item assessment of safety effects ("Sleep problems that affect your ability to work safely?")

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	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
	shipping company (Hansen & Holmen, 2011)	America, Far East, Africa.		sleep disturbances?" "What are the causes of your sleep problems at sea?")		
6	Time-use and related effort study in Dutch short sea shipping (Starren et al., 2008)	31 masters, deck officers, engine officers on board various vessels of Dutch ship owners	Activity/effort survey completed at start and end of each watch period, completed two (for day duty) or four (for those on watch) times a day. In each case activities reported on for preceding on- or off-duty period. Also background survey.	Activity survey: Seafarers log one of 10 categories of activity and associated effort for every 15 minutes on board. Also log time resting, but not sleeping, and sleep quantity/quality. .Background survey: role, working hours, watch schedule, demographics.	Asked about fatigue before and at end of every duty: response scale 1 = not at all; 10 = very fatigued.	How much effort did activity require? Please indicate a number between 1 (no effort) and 10 (extremely high).
7	Factors contributing to fatigue in watch officers on Finnish ships (Accident Investigation Board Finland, 2004)	185 watch officers	Survey and work sleep diary form mailed to all navigator members of the Finnish Ships' Officers' Association; response rate 32 per cent	Demographics, experience as seafarer/as watchkeeper, watch type, time of day, watch system, napping, hours of sleep, sleep disturbances, wakings at night, awake too early, others' observation of apnea, working environment on watch, medicine use, snoring, morning/evening type, how fast you fall asleep, health and dietary behaviours.	Epworth Sleepiness Scale; Skobgy Excessive Daytime Sleepiness (assesses sleepiness generally and relative to friends/colleagues); sleep diary recorded fatigue ratings at different times of day in 4 h phases, on a scale from 1 (not at all tired) to 10 (cannot stay awake). Also fatigue symptom of limbs asleep considered.	Times slept on watch last 5 y, accidents/near misses last 5 y, health status.
8	Diary study to explore factors contributing to fatigue among bridge workers in Finnish shipping. (Accident Investigation Board Finland, 2004)	92 bridge workers.	Background survey, diaries carried by participants.	Background survey of watch system (4/8 vs 6/6), BODY-MASS INDEX, morning/evening type, experience at sea, recent work nature including start-end watch times, start-end times for other work, sleep/wake times, nodding off/ naps.	Karolinska Sleepiness Scale collected every 2 h while on watch (truncated from 9 to 5-pt scale, referred to as alertness); Epworth Sleepiness Scale	
9	Survey of work and sleep of Great Barrier Reef pilots (Australia) (Parker et al., 1998)	35 sea pilots	Survey distributed by three pilot companies, with two reminders. 60 per cent response rate.	Demographics, industry experience, recent work history; sleep patterns at sea/ashore/at home, fitness and illnesses, sleep apnea, sea sickness, lifestyle, heath habits, diet; morning/evening type, vulnerability to decrements, factors causing fatigue, strategies to combat fatigue, job satisfaction.	Chronic fatigue, and feelings on bridge relating to tension and fatigue	Health status and feelings on bridge relating to performance effects of fatigue, impact of performance decrements, specific experiences of incidents.

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	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
10	Work demands and need for recovery in ageing seafarers in UK Royal Fleet Auxillary (Bridger et al., 2010)	n=322 seafarers from 7 ships	Survey by structured interviews (15-30 min) on board. Crew asked to choose time slot 2 weeks prior, 58 per cent response rate. Two months later, participants sent follow-up survey for self-administration.	Physical activity (Baecke Questionnaire) and NASA Task Load Index (TLX) to measure mental, physical, temporal aspects of task/job demands. Effort; own performance and frustration also measured.	Need for Recovery after work (van Veldhoven & Broersen, 2003). Includes indicators of fatigue such as lack of concentration or reduced motivation for activities at end of day.	
11	Watchkeeper alertness on long voyages (Knauth et al., 1986)	25 watchkeepers (4on/8off) on five ships, studied over 3-13 d.	Alertness log carried by participants.	Time of day	Subjective alertness sampled every 4 h while awake using a bipolar visual analog scale: not at all alert - very alert indeed	
12	Work and sleep of marine personnel in US merchant shipping (Thomas F. Sanquist et al., 1997; Sanquist et al., 1996)	141 watchstanders, command (master and chief engineer) and dayworkers (able-bodied seamen, engineers) aboard eight ships.	Recruitment with help of US Coast Guard, response rate 67 per cent. Researchers board ship and ride between ports for ca. 5 d, thorough introduction of project. Primary tool was pocket-sized logbook, for 10 d of data; 1-3 booklets used. Total time to fill out log on any one day was 2 min. Also a background info survey to be filled out in free time (60 min). Mariners paid 50 dollars.	Logbook: sleep timing and quality, sea state, time ship at sea/in port, time in bed, time asleep, time awake, and time up. Sleep quality rated on 1-5 scale, on ease of falling asleep, ease of arising, sleep period sufficiency and sleep depth and restedness. Survey: sleep behaviour on ship / at home, questions on chronic fatigue, personality scales, general health and work habits, means to reduce fatigue.	Retrospective Alertness Inventory (Folkard et al., 1995), rates each hour on a scale of 1 (very alert) to 9 (very sleepy). Ratings at home, at sea, at start and end of sea tour. Logbook also included visual analog scale for alertness, taken before and after sleep, on job.	
13	Impact of watch keeping regimes on sleep, fatigue and safety in Norwegian shipping (Kongsvik & Størkersen, 2011)	382 seafarers surveyed and 43 captains, officers, engineers, seamen tested aboard platform supply vessels contracted by the same Norwegian oil company.	Cognitive and physiological testing of seafarers while on 4 week tour. Seafarers surveyed by sending letters to the vessels' captains, with a letter explaining how the questionnaires should be distributed and returned.	Watch system (6/6 vs 8/8/4/4), objective sleep (actigraph worn for 4 weeks), subjective sleep quality for every episode exceeding 30 min (Karolinska sleep diary; Åkerstedt et al., 1994), food and health behaviours, naps. Questionnaire: 96 items on background info, cooperation/safety prioritisation, management, procedures, work practice, safety information, work safety, competence, working environment, reporting, sleep and rest.	Fatigue items (made up) included in the survey e.g. "after 4 weeks on duty I am worn out", "I feel rested when I have finished my rest period".	Cognitive tests for vigilance and reaction time, accidents and near miss involvement
14	Cardiff Sea Study (UK), extra analysis on causes, prevalence	1855 seafarers in offshore support, short	Combined survey responses from Cardiff Sea Studies I, II and III.	Sea Cardiff Sea Study 1.	Fatigue subscale of the profile of fatigue related symptoms	Cognitive Failures Questionnaire, Health, General Health

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	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
	and outcomes of fatigue (Wadsworth, Allen, & Smith, 2008)	and deep sea subsectors.	Combined survey response rate for whole study, 20 per cent.			Questionnaire and the SF36 General Health Scale
15	Pilot study of fatigue in Northern European "short sea" ferry crews (Reyner & Baulk)	12 seafarers (master, mate, 2nd officer, 2nd engineer, 3rd/4th engineer) examined for one week at sea, then one week at home.	Sleep logs, actigraphs and one-off background questionnaire.	Logs at sea and home: subjective sleep timing and duration, work/rest activities, every day for 7 d. Actigraphs for objective sleep quality/quantity.	Karolinska Sleepiness Scale at sea and at home every 2 h while awake for 7 d.	
16	Impact of short, irregular sleeps at sea on alertness of Great Barrier Reef marine pilots. (Ferguson et al., 2008)	n=17 pilots.	Experimental equipment (logs, palm-tops, actigraphs) and surveys were posted to the pilots homes. Data collected for 28 d periods, which usually includes rest period off tour and work and rest periods on board. Sleep diary filled out after every sleep or nap. Work diary and performance testing were done during work periods.	Location of sleep/nap, start/end times for sleep attempts (lights-off and out of bed), self-rating of sleep quality, start/end times for work. Objective sleep data collected by actigraphy.	Pre- and post-sleep fatigue rating (Samn and Perelli, 1982).	Performance on PVT
17	Sleep and function in watchkeepers on transantalantic voyages. (Condon et al., 1988)	n=15 watchkeepers (4/8) and 28 dayworkers on transatlantic merchant ships (4-5 time zones crossed).	Daily diary records combined with on board measurements	Direction of time zone crossing, sleep quality/quantity, activity quality/quantity. Ratings of sleep quality and oral temperatures taken every 4 h awake.	Subjective alertness.	Two psychological performance tests (letter cancellation and vector tests), every 4 h when awake.
18	Workload and fatigue in US Navy patrol crew. (Grech et al., 2009)	n=20 crew on one Navy vessel, working 4 h watches (3-watch system).	Each participant carried a survey at all times on watch, and filling out every 30 min.	Workload subscale of Crew Status Survey (Pearson and Bryars, 1956; Gawron, 2000), has been validated against NASA TLX.	Fatigue subscale of Crew Status Survey (7pt statement anchored scale, like Karolinska Sleepiness Scale)	
19	Effects of 6/6 and 4/8 systems on bridge officer sleepiness in Finnish shipping (Härmä et al., 2008)	n=185 watch officers	Survey and sleep/work diary sent to representative members of Finnish Maritime Officer Association. Diary completed for 7 d at sea.	Diary: Timing of watch and other duties, sleep quantity/quality, watch system (4/8 vs. 6/6), morning/evening type.	Skogby Excessive Daytime Sleepiness index. Karolinska Sleepiness Scale every 2 h while at watch. Epworth Sleepiness Scale.	Nodding off at work

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	Description	Study population	Data collection	Contributors	Fatigue	Outcomes
20	Fatigue at Sea Wake up to the Dangers (ITF, 1997)					
21	Inductive research on causes of fatigue and comparison of measures of fatigue in US shipboard crew (Pollard et al., 1990)	Trial with a few officers.	Researcher on board, talks with master, who if enthusiastic, encourages mates to take part.	Logs for Workload (7pt anchored scale) sleep timing and activity time study.	7pt subjective fatigue from 1 - fully alert; wide awake to 7 - completely exhausted; unable to function effectively (Samn-Perelli)	
21	Fatigue in US Coast Guard Cutter Crew. (Miller et al., 2003)	Ca. 60 crew on 6 patrols and 3 cutters. 66 per cent watchstanders.	Crew members selected by Department Heads. Daily log integrated from Sanquist et al.'s (1996) log and one created by the Laboratory for Sleep, Fatigue and Safety.	Log: work, rest, sleep times, ship motion, metabolic task demand, ratings of mental (Crew Status Survey) and physical workload, motion discomfort scale, and motivation. Body temperature recorded as indicator of circadian rhythm.	Epworth Sleepiness Scale ("cumulative fatigue") and Stanford Sleepiness Scale("acute fatigue") recorded in log; Watch Fatigue: sleepiness, physical and mental tiredness recorded for typical watch in preceding week .	Cognitive tests performed for visual search, encoding, decoding and rote recall; visual pattern recognition and spatial memory; vigilance; visual temporal acuity; fine motor control and speed.
22	Fatigue in US deck watch officers (DWOs) (Louie & Doolen, 2007)	n=43 DWOs, (masters, chief mates, mates) on large freight ships, public vessels and ferries.	Either interview (on or offshore) or survey.	Info on vessel, prevalence and sources of fatigue. Amount of sleep, consistency of sleep and work periods. Sleep patterns while at port and at sea compared. Also questions relating to automation and stress, and an evaluation of how well regulations are applied.	DWOs asked retrospectively to rate their fatigue at different times during the assignment.	
	Sleep in far sea ship crew (Arendt et al., 2006)	n=14 watchkeepers on 4/8, where 8 worked on weekly rotation to change watch and 6 worked fixed watch times; n=12 dayworkers. Voyage from UK to Antarctica (personnel and Cargo).	Daily sleep diaries, wrist actigraphs worn continuously, urine samples kept.	Time of day, measure of biochemical marker of circadian rhythm in urine sample, subjective / objective sleep quantity and quality (diary/actigraph).	Not measured.	

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Appendix 2 – ITF Waking up to the dangers (1997)

The International Transport Federation (ITF) study (ITF 1997) was influential since it surveyed 2500 seafarers and highlighted cases where respondents were involved in serious accidents, collisions, and near misses when working while exhausted through lack of sleep. Officers regularly reported "dozing off" while in control of fast ferries or of cases where incorrect orders were given. Overfilled cargo tanks, spillages of oil and chemicals and loading errors were common.

One-third of those questioned said they had an average working day of more than 12 hours. Two-thirds had a working week of more than 60 hours, including 25 per cent who worked more than 80 hours a week. Just five per cent reported a decrease in working time over the past 10 years compared with 60 per cent saying hours had increased. It became formally clear as a result of the ITF study that hours on many ships exceeded those laid down in the Standards of Training, Certification & Watchkeeping Convention (STCW), the main regulation covering working hours at sea. This problem has been made worse by the gradual increase in the length of tours of duty to six months and more. This has led to a greater cumulative impact of disturbed sleep and long periods on duty.

Since it did not measure fatigue, the ITF study is not reviewed here.

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