TØI report 1488/2016

Ross Owen Phillips

Institute of Transport Economics
Norwegian Centre for Transport Research

Countermeasures for use in fatigue risk management

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Summary:
Work-related fatigue is a threat to safe transport, but little has been done to structure the complex array of possible mitigating measures that risk managers can consider. To improve the situation, we review the literature to identify and explain 15 countermeasures types, which we then group into five different hazard levels along a “fatigue risk trajectory”. The resulting model helps to structure the choice of countermeasures that together form barriers to fatigue development. The final barrier structure will depend not only on the nature of the transport operation and hazard to be mitigated, but on the resources available to the employer, the current approach to safety risk management, and the scope of fatigue risk management required. Finally, the report identifies questions that need to be answered to improve fatigue management in future transport operations.

Sammendrag:
Arbeidsrelatert trøtthet er en trussel mot sikker transport, men lite er blitt gjort for å strukturere de mange mulige tiltakene mot trøtthet som ledere kan vurdere. For å forbedre situasjonen, gjennomgår vi litteraturen for å identifisere og beskrive 15 forskjellige tiltak mot trøttet. Vi grupperer disse mottiltakene i fem ulike farenivåer langs en «risikobane». Den resulterende modellen bidrar til å strukturere valget av mottiltak som utgjør barrierer til utviklingen av trøtthet i transport. Den endelige barrierstruktur vil være avhengig av type transportoperasjon og faren som må håndteres, og også av arbeidsgiverens tilgjengelige ressurser. Rapporten identifiserer også spørsmål som må besvares for å forbedre trøtthetsstyring ytterligere i framtidens transportoperasjoner.

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Preface

This report is financed by the Research Council of Norway, as part of a strategic investment in TØI's evolving transport safety research program. The work is a continuation of a project on fatigue in Norwegian transport operators, documented by TØI reports 1351, 1354, 1395 and 1440.

Ross Owen Phillips has been project leader and researched and written the report. Beate Elvebakk has quality assured the report and Trude Rømming has prepared the report for publication.

Oslo, August 2016
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Summary:

Countermeasures for use in fatigue risk management

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Increased safety in land- and sea-based transport can be achieved if more employers manage the risks related to operator fatigue. An effective way to do this is to select and apply up to 15 types of countermeasure to manage fatigue along a risk trajectory, beginning with the nature and timing of work and ending with the manifestation of fatigue in incidents and poor health outcomes. The 15 types of countermeasure are: adequate manning; schedule design; breaks and naps; monitoring of actual hours worked; optimisation of work quality; sleep monitoring; health screening and treatment; promotion of recovery from work; recovery monitoring; identification of fatigue symptoms; containment of fatigue while operating; performance assistance; and fatigue-proofing. By grouping these countermeasures according to the location on the risk trajectory of the fatigue hazard addressed, a model of fatigue mitigation is obtained for use in fatigue risk analysis and countermeasure selection by transport risk managers. These managers would be further assisted by knowledge on the effectiveness of interventions using countermeasures, on business drivers for fatigue risk management, and on measures to encourage other transport chain actors to consider fatigue. The use of countermeasures in fatigue risk management has the potential to improve the wellbeing and safety of any employee driving for work.

Work-related fatigue is a threat to safe transport, with considerable environmental, economic and health costs. There is increasing recognition that organisations should do more to manage fatigue in any employee who must operate a vehicle or vessel in the course of their work.

Setting the context: fatigue and its mitigation

There are many definitions of fatigue, but many share the idea that it is a state caused by exertion that can manifest itself physiologically, cognitively or emotionally, and which can affect work performance and health over the shorter or longer term. As there are many possible forms of exertion, safety practitioners must assess fatigue caused by exertion in all aspects of work and non-work life.

Western society is sleeping less than it used to and globalisation demands transport operations at all times of the day or night. At the same time operators must carry out a large variety of tasks, and face increasing competition and tighter deadlines. Due to advances in automation, the main operator task may be becoming more monotonous and there is reason to believe that this will have deleterious effects on both fatigue and safety performance levels. Research studies have surveyed many of the overlapping and interacting factors that influence fatigue, and grouped them as relating to (i) sleep and schedules worked, (ii) occupation or branch being considered, (iii) individual health, (iv) life outside work, or (v) demographics.

There is good evidence linking sleep-related fatigue to poorer performance, and linking sleep-related performance decrements to safety levels. Links between task-related fatigue and operator performance decrements are also established. Despite this knowledge, fatigue continues to cause a substantial share of serious transport accidents and incidents. One possible explanation for this is that too little emphasis has been placed on fatigue management by organisations. Drivers and crew have traditionally been held responsible for managing their own fatigue levels, and legislation has encouraged organisations to focus on the management of hours at work / operating, even though this is only one of several causes of fatigue. Sleep deprivation has also been underappreciated generally as a public health problem.

Fatigue risk management by organisations is a growing trend, promoted by theoretical developments, regulatory changes, and new technology. However, it is still not clear whether there will be wide uptake in the road and maritime sectors. Part of the problem is that there may be under-appreciation of the operational advantages offered by comprehensive risk management, which in turn may be due to a lack of robust evaluation of fatigue risk management interventions.

Reviews conclude that transport organisations wishing to tackle fatigue have tended to rely on one-off countermeasures, most often training courses lasting no more than one day, attempts at schedule management, or screening and treating operators for sleep disorders. While these measures may be effective, there is scope for a more comprehensive and effective approach to fatigue management, even for small outfits with few resources. One way to achieve this is by initiating a fatigue risk management system (FRMS), which is a safety management system focused on a single risk: fatigue. In line with safety management systems, the central tenets of an FRMS are fatigue management policy, fatigue risk management (risk assessment and mitigation), fatigue reporting systems, fatigue incident investigation, fatigue training, and continuous monitoring of system effects.

Fatigue risk management, which is at the core of FRMS, involves selecting countermeasures for fatigue according to standard risk analysis procedures. First, undesirable fatigue-related health or safety incidents will be reviewed and selected, and then prioritised for mitigating action by assessing the likelihood that they will occur and seriousness of their consequences. The causes of prioritised undesirable events will then be assessed, such that countermeasures can be put in place. The mitigation of fatigue is structured most effectively by considering that fatigue manifests itself along a five-step fatigue risk trajectory. The trajectory begins when work causes fatigue (level 1). If the operator then fails to recover from work (level 2), fatigue symptoms become manifest (level 3), and if they are not addressed fatigue-related errors will occur (level 4), which if left unchecked will lead to fatigue-related incidents (level 5). Effective fatigue risk management requires that the risks in each level along this trajectory are monitored and controlled by effective countermeasures.

Review of available countermeasures

The main aim of this report is to review, structure and simplify existing knowledge on countermeasures using knowledge available in the peer-reviewed literature. In particular, we identify and describe 15 groups of countermeasures, arranged according to where along the risk trajectory the mitigated fatigue hazard is located. The countermeasures and corresponding hazard levels are shown in figure S1.

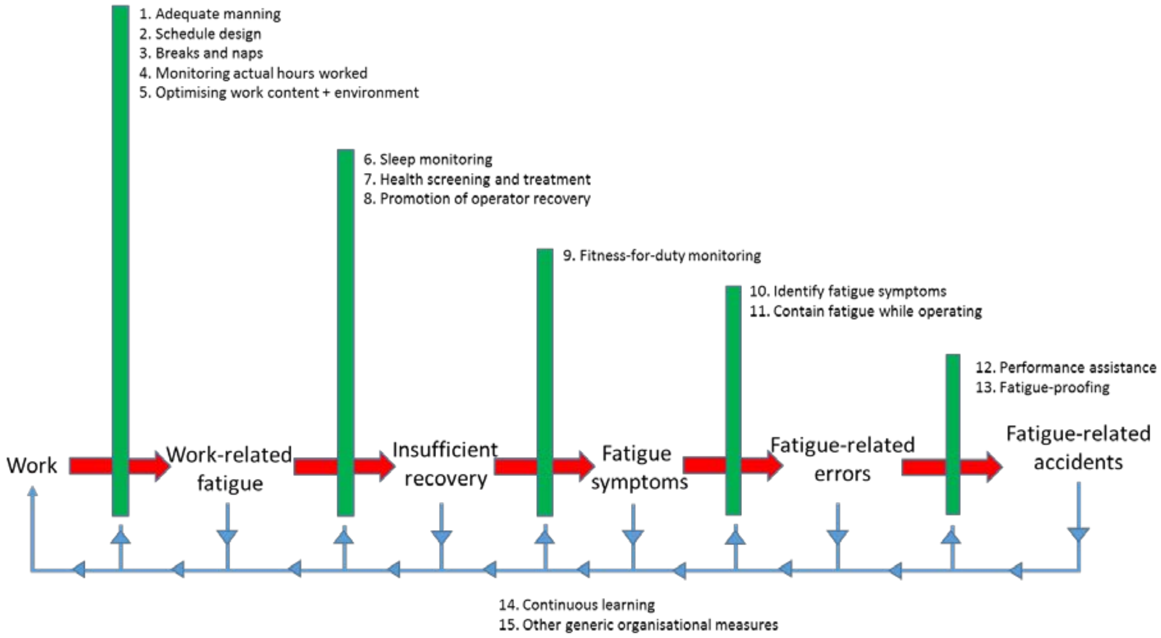

Figure S1. Countermeasure groups for fatigue in human transport operators arranged along a fatigue risk trajectory. After an initial risk analysis, barriers (in green) should be put in place to minimise the chance that work causes fatigue-related accidents. The manifestation of fatigue should be monitored at each step of the trajectory, and used to evolve and evaluate the barriers preceding that step, as indicated by the blue arrows.

Each of the countermeasures 1-15 in Figure S1 is explained and exemplified in Table S1. The particular choice of countermeasure and final barrier structure will depend not only on the nature of the transport operation and hazard to be mitigated, but on the resources available to the employer, the current approach to safety risk management, and the scope of fatigue risk management required.

Countermeasure effectiveness and future research needs

Countermeasures which have been shown to affect fatigue outcomes should be prioritised. These include job design interventions, health screening and treatment, and stopping to sleep or drink caffeine during longer operating periods. More evaluations are required to compare interventions with different types of countermeasure or barrier on standard outcome measures, in order to be able to rank countermeasure combinations in terms of effectiveness. Evaluations of implementations of whole systems of fatigue risk management are also required.

Answers to the following questions are also needed to promote effective fatigue risk management by transport employers:

- What evidence is there that fatigue risk management brings business benefits to employing organisations? On a related point, what drives employers to implement fatigue risk management systems?
- What opportunities are there for centralised monitoring of employee fatigue as it manifests itself along the risk trajectory?
- What role can transport buyers or other transport chain actors play in fatigue risk management, and how can their participation best be encouraged?.

- How can the experience and knowledge of consultant practitioners in fatigue risk management be made more widely available to better map the
- possibilities available to organisations wishing to manage fatigue risks in transport operators?

Table S1. Specific examples of each countermeasure group, one for a simple approach to fatigue risk management by a company with limited resources, and one for a comprehensive approach where more resources are available.

Countermeasure group		Example of specific countermeasure	
		Simple approach	Comprehensive approach (e.g. FRMS)
1	Adequate manning	Increase number of operators	Increase number of operators
2	Schedule design	Use of simple formula or guidelines	Schedule optimisation based on biomathematical modelling software with input data on actual sleep times
3	Breaks and naps	Plan rest stops in advance	Evaluation of strategic napping intervention
4	Actual hours worked	Compare self-reports / logs of actual working hours with planned schedules	Analyse change in fatigue risk index for actual schedules worked versus those planned
5	Optimise work content	Simple survey to identify and reduce secondary tasks causing fatigue	Human factors / task analysis and optimisation by independent consultant
6	Monitor actual sleep	Wearables giving feedback and tips on sleep improvement via mobile app	Centralised collection of actigraph data to feed into schedule design
7	Health screening and treatment	Develop fatigue checklist in collaboration with doctor to be used at annual check-up	Monthly screening by occupational health service with follow up of disorders influencing fatigue
8	Promote operator recovery	Provide taxi to/from ship/depots after long operating periods	Sleeping facilities at depots, sleep contracts, family training
9	Monitor fitness-for-duty	Mobile app-vigilance test	Vigilance test with results fed into FRMS
10	Monitor fatigue symptoms while operating	Self-assessment with Tiredness Symptoms Scale	Embedded performance monitoring, facial/eye technology
11	Contain fatigue while operating	Promote stopping and sleeping	Promote stopping and sleeping
12	Performance assistance technology	-	Requires further validation
13	Fatigue-proofing	Increase customer awareness and involvement	Technological safeguards
14	Continuous learning	Regular review and optimisation of countermeasures	Safety assurance, data-driven evaluation of each risk level at regular meetings
15	Other organisational measures	Recruitment	Safety culture development Needs analysis

Sammendrag:

Tiltak mot trøtthet for bruk i risikostyring

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Økt sikkerhet i land- og sjøbasert transport kan oppnås dersom flere arbeidsgivere overvåker og styrer risikoene knyttet til trøtthet blant transportoperatører. Som del av sin risikostyring kan arbeidsgivere anvende opptil 15 typer av tiltak mot trøtthet; tilstrekkelig bemanning, tidsplandesign, tilstrekkelige arbeidspauser, overvåking av faktiske arbeidstimer, optimalisering av arbeidskvalitet, søvnovervåking, helsescreening og behandling, tilrettelegging for restitusjon, identifisering av trøtthetssymptomer før eller under arbeid, begrensning av trøtthet under drift, «performance assistance», og «fatigue-proofing». Mottiltakene kan grupperes langs en «risikobane» som begynner med arbeidets egenskaper og slutter med manifestasjon av trøtthet i hendelser og dårlige helseutfall. På denne måten får man en modell som ledere kan bruke for å overvåke og styre trøtthetsrisikoer. For å forbedre situasjon ytterligere er det behov for mer kunnskap om effektene av mottiltak, om hva som fremmer bedriftens implementering av systemer for overvåking og styring av trøtthetsrisikoer, og om tiltak for å oppmuntre andre aktører i transportkjeden å vurdere trøtthet. Dette er viktig fordi bruk av mottiltak for å overvåke og styre risikoene knyttet til trøtthet har potensial til å forbedre velferd og sikkerhet blant alle som må kjøre i arbeid, enten de er yrkessjåfører eller ikke.

Arbeidsrelatert trøtthet er en trussel mot sikker transport, med betydelige miljømessige, økonomiske og helsemessige kostnader. Det er økende erkjennelse av at organisasjoner bør gjøre mer for å håndtere trøtthet blant arbeidstakere som opererer kjøretøy eller fartøy i sitt arbeid. Mange hevder at dette kan gjøres mest effektivt ved å ta hensyn til trøtthet i arbeidsgiverens risikostyring, men lite er blitt gjort for å strukturere de mange mulige tiltakene mot trøtthet som ledere kan vurdere som del av denne prosessen. Målet med denne rapporten er å gjennomgå og forenkle valg av tiltak mot trøtthet for bruk i organisatorisk risikostyring.

Trøtthet og risikostyring sett i sammenheng

Det finnes mange definisjoner av trøtthet, men mange deler ideen om at det er en tilstand forårsaket av anstrengelse som kan manifestere seg fysiologisk, kognitivt eller følelsesmessig, og som kan påvirke arbeidsprestasjoner og helse på kortere eller lengre sikt. De som ønsker å overvåke og styre trøtthetsrisikoer bør huske at det er mange mulige former for anstrengelse som forekommer både på jobb og i livet utenfor jobb.

Globalisering krever transportvirksomhet til alle døgnets tider. Samtidig må operatører gjennomføre flere oppgaver, i møte med økende konkurranse og mer tidspress. På grunn av fremskritt innen automatisering, blir hovedoppgaven (kjøring eller brovakt) mer monoton, og det er grunn til å tro at dette kan føre til økt søvnighet og dårligere sikkerhetskritisk ytelse. Forskning har kartlagt mange av de overlappende og interagerende faktorer som påvirker trøtthet, og gruppert dem i forhold til (i) søvn og tidsplaner, (ii) yrke eller transportbransje, (iii) operatørens helse, (iv) livet utenfor jobb eller (v) demografi.

Flere studier knytter søvnrelatert trøtthet til redusert ytelse blant sjåfører og andre operatører, og knytter også redusert ytelse til lavere sikkerhetsnivåer. Koblinger mellom oppgaverelatert trøtthet og redusert ytelse er også etablert. Til tross for denne kunnskapen forårsaker trøtthet fortsatt en vesentlig andel av alvorlige transportulykker. En mulig forklaring på dette er at arbeidsgivere har lagt for lite vekt på trøtthetsstyring. Førere og sjømannskap har tradisjonelt blitt holdt ansvarlig for sine egne trøtthetsnivåer, og lovverket oppmuntrer til et fokus på timer på jobb eller i drift, selv om arbeidstid kun er én av flere årsaker til trøtthet. Samtidig har søvnmangel også blitt undervurdert som et folkehelseproblem generelt.

Organisatorisk overvåking og styring av trøtthetsrisikoer er en voksende trend, drevet av teoretisk utvikling, regulatoriske endringer og ny teknologi. Men det er fortsatt ikke klart om systemer for trøtthetsstyring vil få stor utbredelse i vei- og maritim sektor . En del av problemet er at man kan undervurdere de operative fordelene ved en helhetlig risikostyring, noe som igjen kan skyldes manglende evaluering av intervensjoner.

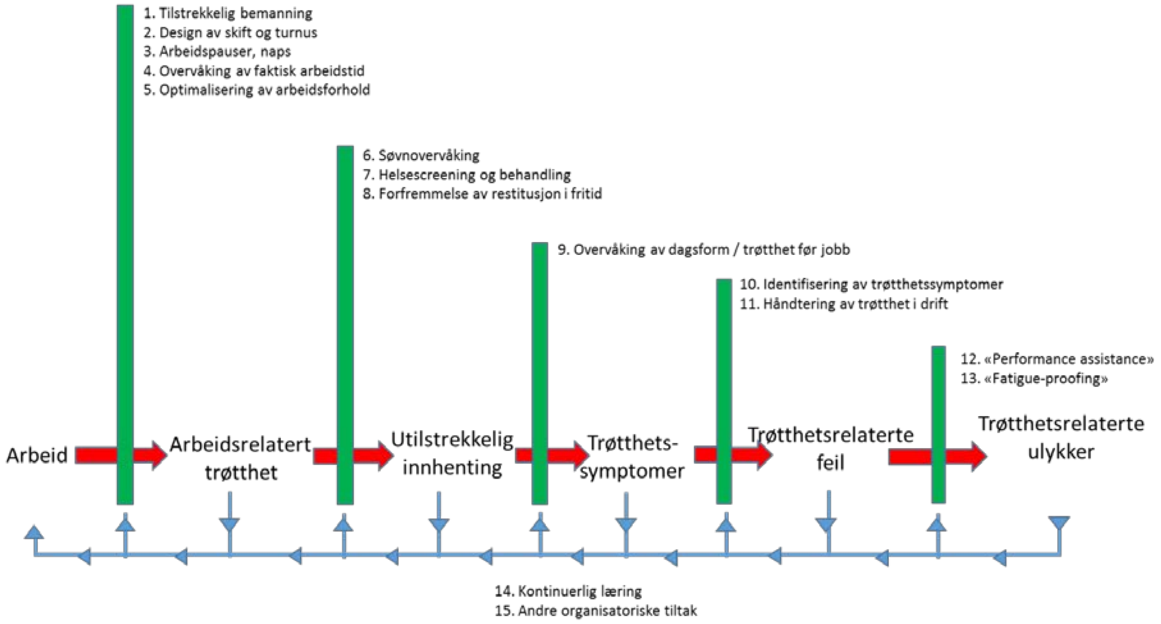
Forskere konkluderer med at transportorganisasjoner som ønsker å takle trøtthet har hatt en tendens til å satse på engangstiltak, oftest opplæringskurs, skift- og turnusanalyser, og helsescreening og behandling av operatører. Selv om disse tiltakene kan være effektive, er det ofte rom for en mer helhetlig og omfattende tilnærming til trøtthetstyring, selv for små bedrifter eller rederier med få ressurser. En måte å oppnå dette på er ved å implementere et risikostyringssystem for trøtthet (*Fatigue Risk Management System*, FRMS).

FRMS er et sikkerhetsstyringssystem med fokus på trøtthet. I tråd med sikkerhetsstyringssystemer, er de sentrale prinsippene for en FRMS en policy for trøtthet, en prosess for risikostyring for trøtthet (risikovurdering og -reduksjon), rapporteringssystemer for trøtthet, granskning? av trøtthetsrelaterte hendelser, trøtthetsopplæring, og kontinuerlig overvåking av systemeffekter.

Risikostyring er kjernen i FRMS, og det innebærer valg av tiltak mot trøtthet i henhold til generiske risikoanalyseprosedyrer. Først vil uønskede trøtthetsrelaterte helse- eller sikkerhetshendelser bli identifisert, og deretter prioritert ifølge sannsynligheten for at de inntreffer og alvorlighetsgraden av konsekvensene. Årsakene til prioriterte uønskede hendelser vil da bli vurdert, slik at mottiltak kan innføres (eller settes inn). Vi tenker oss at trøtthet manifesterer seg langs en fem-trinns «risikobane». Banen begynner når arbeid fører til trøtthet (nivå 1). Hvis operatørene deretter ikke klarer å hente seg inn før de begynner på neste arbeidsøkt (nivå 2), vil trøtthetsymptomer bli manifeste (nivå 3), og hvis de ikke blir håndtert vil trøtthetsrelaterte feil oppstå mens de opererer (nivå 4). Hvis disse feilene ikke er kontrollert vil de føre til trøtthetsrelaterte hendelser (nivå 5). Effektiv risikostyring innebærer at risikoene i hvert nivå langs risikobanen blir overvåket og kontrollert av effektive mottiltak.

Gjennomgang av tilgjengelige mottiltak

Hovedformålet med denne rapporten er å gjennomgå og forenkle eksisterende kunnskap om mottiltak. Vi identifiserer og beskriver 15 grupper av mottiltak, ordnet etter hvor langs risikobanen den tilsvarende trøtthetsfaren ligger. Mottiltak og tilhørende farenivåer er vist i figur S1.



Figur S1. Grupper av tiltak mot trøtthet i menneskelige transportoperatører arrangert langs en risikobane. Etter en innledende risikoanalyse, bør barrierer (i grønt) innføres/opprettes for å minimere sjansen for at arbeidet fører til trøtthetsrelaterte ulykker. Manifestasjonen av trøtthet bør overvåkes ved hvert trinn langs risikobanen, og brukes til å evaluere og utvikle de foregående barrierene (blå piler). Hver av mottiltakene 1-15 i figur S1 er forklart og eksemplifisert i tabell S1. Det spesifikke valget av mottiltak og barriere er avhengig ikke bare av transportens natur, men arbeidsgiverens ressurser, eksisterende tilnærming til sikkerhetsstyring, og omfanget av risikostyring som er påkrevd.

Effektivitet og fremtidige forskningsbehov

Mottiltak som har vist seg å virke på trøtthet og trøtthetsrelaterte utfall bør prioriteres. Disse omfatter intervensjoner som inkluderer jobbdesign, helsescreening og behandling, stopping og soving eller å drikke koffein under lengre driftsperioder. Det trengs flere evalueringer for å kunne rangere kombinasjoner av mottiltak etter effektivitet. Evalueringer av hele FRMS-systemer er også nødvendig.

For å fremme styring av trøtthetsrisikoer hos transportorganisasjonen, trenger vi også svar på følgende:

- Hvilket belegg er det for at risikostyring gir økonomiske og andre organisatoriske fordeler for arbeidsgiveren? Og hva får arbeidsgivere til å implementere FRMS?
- Hvilke muligheter finnes for sentralisert overvåking av operatørens trøtthet slik den manifesterer seg langs «risikobanen»?
- Hvilken rolle kan transportkjøpere og andre deltakere i transportkjeden spille i risikostyring? Hvordan stimulere deltakelse og interesse?
- Hvordan kan praktisk erfaring i trøtthetsstyring bli kartlagt og fordelt for å øke kunnskap om gode løsninger blant de som ønsker å redusere trøtthetsrisikoer i transport?

Tabell S1. Spesifikke eksempler på hver gruppe av mottiltak, én for en enkel tilnærming til risikostyring, f eks i et selskap med begrensede ressurser, og én for en helhetlig tilnærming der flere ressurser er tilgjengelige .

Gruppe av mottiltak		Eksempler på spesifikke mottiltak	
		Enkel tilnærming	Omfattende tilnærming (f eks FRMS)
1	Tilstrekkelig bemanning	Økt antall operatører	Økt antall operatører
2	Design av skift / turnus	Bruk av enkel algoritme eller veiledning	Optimalisering av tidsplan basert på biomatematiske modeller basert på data på faktiske søvntimer
3	Pauser	Planlegging av hvile og pauser på forhånd	Evaluering av strategisk "nap" intervensjon
4	Faktiske arbeidstimer	Sammenligning selvrapporteringer / registreringer av faktisk tid i arbeid med -planlagte tidsplaner	Analysere endring i indeksen for trøtthetsrisiko for faktisk vs planlagt arbeidstid
5	Optimalisering arbeidsinnhold	Enkel survey for å identifisere og redusere sekundære oppgaver som forårsaker trøtthet	Human factors / oppgaveanalyse ved selvstendig konsulent
6	Overvåking av søvn	Wearables som gir tilbakemelding og tips på forbedring av søvn via mobilapp	Sentralisert innsamling av data fra aktigraf som innspill til utforming av tidsplanene
7	Helsescreening og behandling	Utvikle sjekkliste for trøtthet i samarbeid med lege, for bruk i årlig helsekontroll	Månedlig screening ved BHT med oppfølging av søvnforstyrrelser
8	Tilrettelegging for restitusjon i fritid	Sørge for taxi til/fra skip/depot etter lange driftsperioder	Søvnhotell på depoter, søvnkontrakt, opplæring av familier
9	Overvåking av dagsform / trøtthet før jobb	Test for årvåkenhet på mobil	Test for årvåkenhet med data brukt som innspill til FRMS
10	Identifisering av trøtthetssymptomer mens man opererer	Selvrapporteringer f eks ved bruk av "Tiredness Symptoms Scale"	"Embedded performance monitoring", ansikts-/øyeteknologi
11	Takle trøtthet som utvikler seg mens man opererer	Oppfordre til og muliggjøre "stopp og sov"	Oppfordre til og muliggjøre "stopp og sov"
12	"Performance assistance technology"	-	Ytterligere validering trengs
13	"Fatigue-proofing"	Øke kundenes bevissthet og engasjement	Teknologiske sikringstiltak
14	Kontinuerlig læring	Regelmessig gjennomgang og optimalisering av mottiltak	Sikkerhetssikring, datakjørt evaluering av risikonivåene på regelmessige møter
15	Andre organisatoriske tiltak	Rekruttering	Utvikling av sikkerhetstiltak Behovsanalyse

1 Introduction

Transport operator fatigue is a threat to safe transport by road (Williamson & Friswell 2013), rail (Dorrian et al. 2007), sea (Akhtar & Utne 2015) and air (Caldwell 2001). It has considerable environmental (Folkard & Tucker 2003, Smith 2006, Bidasca & Townsend 2014) and health costs (Rohr et al. 2003, Moreno et al. 2006, Lie et al. 2014). It is not a new problem, but there are claims that more should be done to tackle operator fatigue, not least by transport companies who are well placed to monitor and control the fatigue of their employees (Phillips & Sagberg 2010).

Attempts can be made to manage and control fatigue at organisational level, using safety management systems, which are evidence-based risk assessment and mitigation procedures anchored in company policies, roles and documents. Management commitment to safety, a positive safety culture and continuous learning are seen as necessary elements for the success of such systems (Lerman et al. 2012). The extent to which safety management systems are implemented in particular transport companies will depend on available resources, regulatory contexts and the importance of safety to the business (Nævestad 2016).

Dawson & McCulloch (2005) explain that the risks associated with fatigue can be described as lying along a trajectory – the "fatigue risk trajectory" – in which the quality and timing of work influences not only the extent of employee fatigue, but recovery from fatigue, fatigue-related symptoms and behaviour, and ultimately incidents and accidents. Further, they explain that in order to manage fatigue risks effectively, transport companies need to monitor and mitigate fatigue risks along the whole range of this trajectory, as part of their risk assessment process. Thus, for example, it is not enough to simply limit the numbers of hours worked and ensure there is adequate opportunity for sleep; companies should also monitor whether employees have actually recovered from fatigue before they start work, and whether any fatigue symptoms develop while they are at work. This comprehensive approach, rooted in Reason's (1997) Swiss Cheese model, is recognised as an effective way to mitigate fatigue.

When seeking to mitigate individual fatigue risks along a trajectory, transport risk managers are faced by a complex array of possible countermeasures. This is complicated further by rapid developments in technology, such as biomathematical modelling software or wearables. While several useful reviews of fatigue management strategies exist, they are of limited use to the risk practitioner working in a transport company, in that they consider neither countermeasures by risk level nor the particular challenges of transport (Belenky et al. 2011, Lerman et al. 2012, Rose & Giray 2013, May & Baldwin 2009, Balkin et al. 2011). Williamson & Friswell (2013) have reviewed the state of knowledge on fatigue countermeasures for general work-related fatigue within an occupational health and safety framework, and conclude that little is known about the effects of fatigue countermeasures on safety or health. Starren et al. (2008) classify reactive and proactive fatigue measures specifically for the maritime sector. In a recent review, Anund et al. (2015) discuss countermeasures in the context of a chain of decisions that need to be made in order to mitigate crash risks in different transport sectors, and cover for each sector topics such as laws and regulations, self-administered countermeasures, technical solutions and the risk implications of transport infrastructure.

The current report makes a unique contribution by focusing on appropriate countermeasures for fatigue risk mitigation by transport organisations. It discusses the application of countermeasures in relation to the risk(s) they address in the context of the fatigue risk trajectory. By doing so it will be useful to any company wishing to manage fatigue as a risk as part of a simple or comprehensive safety management system. Such companies include in addition to those employing professional operators like bridge officers or truck drivers, any company employing people who operate vehicles or vessels in the course of their work, e.g. emergency services, sales people, plumbers, delivery van drivers or nurses on call. These non-professional drivers who must drive for work, or to or from work, are receiving increasing focus as subjects for fatigue risk management (ETSC 2011). In considerations of fatigue risk management, insufficient consideration has also been given to the reality of many transport operations as small, independent outfits with limited resources (Nævestad 2016). This is especially the case in the haulage and maritime sector, but even in the rail sector there may be independent owner drivers (Phillips et al. 2015). A further concern of this report is therefore to highlight simple, effective measures that can be used for fatigue mitigation in these sorts of outfits.

This report does not include countermeasures for implementation by road administrations, such as stop-and-sleep campaigns or rumble strips.

Structure of the report

In the next chapter we set the context for our review of countermeasures, by using our existing knowledge of the literature to explain what fatigue is and why it needs to be addressed. We explain how traditional countermeasures are being supplemented by ways of addressing the systemic risks, and present a template for thinking about systemic risks – a version of the fatigue risk trajectory adjusted to account for our particular operationalization of fatigue. The findings from the literature review of available countermeasures in the context of fatigue risk management are then presented in Chapter 3. Finally, in Chapter 4 we discuss the implications of the review for practitioners wishing to manage fatigue in today's transport companies. We also consider some issues for the future.

In the report we refer to fatigue-inducing factors, which we define as any factor likely to increase fatigue, either by itself or in combination with other factors. The term "operator" is used to describe someone in direct or indirect control of a vessel or vehicle that is transporting goods or passengers, rather than a company.

2 Setting the context: Fatigue and its mitigation

2.1 What is fatigue?

There are many different definitions of fatigue, but many share the idea that it is a state caused by exertion (Phillips, 2015). Given this, a simple definition of fatigue is:

"*Fatigue is the body-mind response to sleep loss or to prolonged physical or mental exertion.*"

A similar but more comprehensive definition, explains the dynamic and multifaceted nature of the exertion that can cause fatigue (Phillips, 2015):

"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. [This in turn depends on] 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…

Accepting this definition, we note the following:

- Fatigue is a broad condition that can manifest itself physiologically, cognitively or emotionally, and which can affect health and/or performance in the short or longer term.
- Since fatigue manifests itself in different ways, there are several ways to measure it (Phillips 2015). It can be monitored through observation of drowsiness behaviour, self-reports of weariness, or by cognitive or physiological measurements.
- Being caused by exertion, fatigue differs from the tiredness that results from normal sleep drives (Åkerstedt et al. 2004). Importantly, however, we consider that fatigue occurs whenever one is motivated to work or otherwise exert oneself when one would otherwise be asleep (e.g. after not having slept for a long time or through the circadian nadir), and include the effect of sleep drives as part of the fatigue condition and experience in those situations. In this way we consider sleep drives to be an important aspect of fatigue. This way of thinking is in line with May & Baldwin's (2009) treatment of fatigue, which encompasses both sleep- and task-related fatigue.
- Since there are many forms of exertion, the above definition encourages practitioners to mitigate the effects of fatigue on health and performance by attending to fatigue caused by exertion in all aspects of an operator's work and non-work life.

2.2 Increasing need to address operator fatigue

Members of industrialised populations are sleeping less than they used to. According to the US Sleep in America poll, 67 % of the population felt it was getting enough sleep in 1991 versus only 56 % in 2013 (National Sleep Foundation 2012). One third of US society is now estimated to suffer from some form of insomnia, and nine % have been formally diagnosed with a sleep disorder (Ford et al. 2015; Le Blanc 2009; National Sleep Foundation 2015). While round-the-clock societies are better able to compete in a globalised world, members of those societies often work more when they should be asleep and sleep more when they should be awake (Bergene et al. 2014).

The latter applies not least to transport operators, many of whom have also become subject to demanding shift arrangements in attempts to improve productivity (e.g. split shifts) (Phillips & Bjørnskau 2013). While seafarers have always had challenging shift arrangements, they face increasing workloads and manning cuts (Smith et al. 2008). Truck drivers face increasing competition and delivery pressures, which they must often cope with alone (Enehaug & Gamperiene 2010), while bus drivers must increasingly balance demands for punctuality with those for safety and customer service (Kompier 1996).

In a parallel development, many operator tasks have become more challenging, not least due to increasing automation. Bridge officers face periods of intense activity (e.g. port calls), followed by long monotonous periods as passive monitors, where there is a need for continuous alertness. In road transport, promises of partial automation of the driver task and associated strategies such as "platooning" may also increase fatigue risks due to the need for passive vigilance under monotonous conditions, where the operator is still expected to intervene and take control of the system in case of emergencies (May & Baldwin 2009, Desmond & Hancock 2001).

Today fatigue continues to cause sleepiness, behavioural and cognitive decrements, and a substantial share of serious accidents (Williamson et al. 2011, Phillips et al. 2015), and it seems like it will remain a threat to safe operation across transport sectors for some time to come. In addition to safety concerns, operator fatigue also increases the potential for environmental disasters, especially at sea, where it is a major cause of ship groundings (Smith 2006, Akhtar & Utne 2014). It has long-term health implications for operators, for example by exacerbating obesity, musculoskeletal problems and long-term stress outcomes (Rohr et al. 2003, Moreno, et al. 2006). It can have economic costs due to fines for accidents, losses, health costs and increased insurance premiums (Folkard & Tucker 2003, Bidasca & Townsend 2014).

2.3 Reasons why fatigue has not been tackled

There are several reasons why transport operator fatigue has been inadequately tackled to date.

- Sleep deprivation has long been recognised as an unmet public health challenge, partly due to serious misconceptions, such that it is possible to fully recover from several nights of poor sleep with one good night of sleep (Lerman et al. 2012).

- In road transport, drivers have been held responsible for their own alertness, in accordance with road traffic laws, and there has been a lack of accounting for systemic factors such as strict delivery deadlines set by shipping agents, or even problems imposed by "unphysiological" driving time regulations (Phillips et al. 2015).
- In sea transport there is a traditional culture of not letting colleagues down whatever the costs, and recognition that fluctuations in operational phases make fatigued work inevitable (Phillips et al. 2015).
- In many transport sectors, fatigue is still managed by measuring hours worked and rested (rule-based regulation), rather than demands of work, recovery from work and actual fatigue symptoms (goal-based regulation) (McCulloch et al. 2002).
- It has until recently been difficult to measure operator sleep objectively (but "wearable" technologies and smart phone apps are now rapidly expanding the possibilities).
- The problems of measuring fatigue have been emphasised to the detriment of what actually is possible (Phillips 2014a).

Increasing recognition of these points by regulators and organisations has made fatigue risk management systems more appealing, and more and more transport authorities are publishing guidelines and legislation to encourage implementation of these systems. The parallel development of organisational safety management systems is also making systematic management of risks associated with fatigue increasingly attractive for in the road, rail and maritime sectors.

2.4 Fatigue-inducing factors (FIFs)

According to several reviewers, employee fatigue is influenced by individual, job and environmental factors (Williamson & Friswell 2013). We may consider these as different groups of fatigue-inducing factors (FIFs), which have been defined as those that "shift the fatigue-risk distribution in the direction of increasing risk of error, incident or accident" (Williamson & Friswell 2013). Examples of individual factors are an individual's sleep-wake history, diet, health, fitness and motivation to perform. Examples of job-related influences are task duration, task complexity, the degree of job monotony or demand for sustained performance (Williamson & Friswell 2013). Examples of environmental FIFs are noise and motion in the maritime sector, and the seating position of bus drivers.

Williamson & Friswell (2013) summarise FIFs for which there is evidence for effects on fatigue. They find that two main work-related FIF groups can be described according to whether they describe how work is organised or the type of work done. FIFs that relate to how work is organised include total work time and recovery, time on shift, breaks, shift type, and shift pattern. Shift patterns can describe the number of consecutive shifts and whether shifts are fixed or rotating – both are important FIFs. Due to the need to provide round-the-clock transport facilities, shift-related FIFs are important to consider for transport operators (Brown 1997).

Phillips (2014b) classifies the most common FIFs considered by researchers studying fatigue in human operators in land and sea-based transport sectors (table 1).

Table 1. Examples of different types of fatigue contributors studied that contribute to fatigue, according to sector of fatigue study. Taken from Phillips (2014b).

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

The FIFs are grouped according to whether they are related to (i) sleep and schedules worked, (ii) the particular occupation or transport branch being considered, (iii) individual health; (iv) life outside work; or (v) demographics.

As expected, applied transport studies place particular emphasis on how work is organised, but also appear to place a lot of emphasis on surrounding branch conditions. This implies that there are particular causes of fatigue that are unique to particular transport branches, which those applying countermeasures also need to account for. Examples are the frequency of port calls, found to influence fatigue in the maritime sector, or pay systems or the availability of resting places, which may be expected to influence driver fatigue in road transport (Lützhöft et al. 2007, Askildsen 2011).

Table 1 illustrates that a large array of FIFs have been studied, that they often overlap with each other, and that they vary widely in specificity. For example, working time will influence both the duration of tasks performed and opportunity for sleep. Another important point is that FIFs will often be present together and interact to influence fatigue (e.g. health status, age and sleep quality). Relatively little is known about how the history of dynamic variations among different FIFs combine to cause fatigue. A possible exception, and perhaps the most important interaction, is that between the two main sleep cycle drives.

Most accept that main effects of sleep drives are well described by the 2-process model (Borbély 1982), in which sleep onset is predicted by the function of (i) homeostatic drives and (ii) circadian drives. The homeostatic drive towards sleep increases with time since last sleep, and is restored (up to a certain threshold) with time spent asleep. Thus, if you had too little sleep last night and have been awake for a long time, your homeostatic drive for sleep will be high. The circadian drive is a sinusoidal function that programs sleep to occur during the night and to stop during the day. It is influenced by external factors, in particular light/dark cycles. In people who normally sleep at night, the circadian drive is highest during the circadian "dip", between 0200 am and 0600 am. (e.g. Borbély 1982, CASA 2014). More recently, there is acceptance for a 3-process model, which includes the drive for waking (Akerstedt & Folkard 1995). Where this drive has not peaked it causes sleep inertia, where people feel sleepy on waking. Inadequate sleep time and misalignment of circadian rhythm are the "most significant contributors to disastrous human error in the work place" (Rose & Giray 2013).

The challenge for the risk manager will be in identifying the most important FIFs to control. Here there are several important questions to answer.

- What is the evidence that the factor of interest actually influences fatigue? A related question is how can the effect of this factor on fatigue be isolated from the effects of multiple interacting factors? Such questions may not be easy to answer where there are a lack of conclusive studies linking potential FIFs and fatigue.
- Can the FIF be monitored by the organisation? Many have called for actual hours of sleep to be monitored, but this has not been practically possible until recently.
- Can the factor be reasonably manipulated by the organisation? There is little an organisation can do about lack of sunlight or the lack of resting places along the road, but it can limit hours spent loading, for example.

2.5 The effects of fatigue

Several fatigue-related outcomes may be important to the transport organisation. Safety outcomes may be measured in terms of safety performance at several levels. At the cognitive level, there may be slowed reaction time, reduced vigilance, reduced access to knowledge and decision-making ability, poor judgment, increased reliance on mental schemas in deviant situations, or loss of situational awareness (Horne 2012, Lerman et al. 2012, Gunzelmann et al. 2012, Lim & Dinges 2010). At the behavioural level, operators may be less likely to attend to important information or communicate effectively, there may be navigational command errors at sea or there may be poor handling of the road vehicle or train (Phillips 2014a). At the organisational level there may be a higher frequency of fatigue-related accidents or near misses. There will also be health outcomes, which can be assessed at the individual level using questionnaires or medical checks. At the organisational level health effects may be assessed in terms of sickness absence or employee attrition (Backman 1983). There will also be economic outcomes, e.g. in terms of insurance claims made by the organisation, health claims, or in terms of fleet maintenance costs.

Much of the evidence on fatigue related outcomes comes from experimental or simulator studies, but increasingly from field or naturalistic studies. Reviewing evidence for the links between fatigue and safety outcomes, Williamson et al. (2011) conclude the following:

- Links between (i) inadequate sleep (homeostatic pressure) and poorer performance and (ii) from sleep-related performance decrements to reduced safety are established.
- The link between task-related fatigue (especially tasks requiring sustained attention like most operator tasks) and performance is established, but not from performance decrements to reduced safety.
- Links between circadian rhythm and performance and safety are not established, partly due to the difficulties of isolating such effects from homeostatic or task influences.

Dawson et al. (2012) add that we do not have enough evidence linking cognitive impairment to accidents and injuries, or the way in which fatigue-induced errors of cognition are translated into unsafe behaviours and thus accidents and injuries.

There have been few attempts to establish concrete links between different forms of fatigue and fitness for duty, and this is confounded by interactive effects of fatigue, stress and poor health (Phillips & Bjørnskau 2013). There is, however, a large body of literature on the effects of shift work on various health conditions, such as cancer, metabolic disorders and psychological problems (Costa 2010), which leads one to question the extent to which transport companies consider the long-term health risks of work-related fatigue on their employees. This is made all the more important if one considers that poor health can lead to decreased safety performance.

2.6 Traditional approaches to fatigue containment

Hours of Work legislation

Hours of work regulations provide clear upper limits for the amount of time employees can spend working. Additional regulations account for the circumstances of particular transport operator tasks e.g. EU driving regulations or the aviation industry's Flight and Duty Time Limitation schemes (CASA 2014). In some countries there may also be local agreements between unions and employers that tailor these arrangements to local conditions, within the confines of EU law. Whatever the case, the main effect of such regulation approaches is prescriptive limits on working or operating time.

Prescriptive approaches are criticised in that they encourage managers to focus on and measure working hours, and in doing so fail to account for actual recovery from work (e.g. time spent sleeping), or the monitoring of the actual fatigue levels (Feyer & Williamson 1995, Phillips & Sagberg 2010). Such factors include variations among individual operators, varying operational demands, commuting, or the demands of life outside work (Fourie et al. 2010, Phillips & Sagberg 2010).

Attempts are being made to deal with these criticisms by modifying the regulations, with some success, and prescriptive legislation remains the main and arguably most successful measure against fatigue in transport operators (van Dongen & Mollicone 2014). Most forms of prescriptive legislation remain inadequate, however, as evidenced by the major transport accidents that continue to occur due to operators who are fatigued but who nevertheless have complied with hours of driving legislation (e.g. AIBN 2014). It is also strange that despite agreement with current scientific understanding about how much sleep is required for people to function at a reasonable level, there are large and important differences between sectors as regards working time regulations that seek to limit fatigue (Anund et al. 2015). An additional argument for the need to supplement regulations can be found in the fatigue risk trajectory, which says that fatigue is best controlled by attending to and managing risks at each of five levels, only one of which is addressed by the regulations. We shall say more about this in Section 2.9.

Publicity campaigns

Several studies find that most drivers know what to do to reduce fatigue (stop and sleep) but in practice they often favour more ineffective countermeasures (Nordbakke & Sagberg, 2007). Campaigns informing drivers about the symptoms of fatigue and what to do about it may therefore be only of limited use. Moreover, such campaigns do not attend to the systemic restraints placed on drivers.

2.7 Fatigue management by transport organisations: A growing trend

Before the 1990s most attempts at managing fatigue at the organisational level were limited either to driving hours prescription or fatigue education programmes. The latter often listed simple countermeasures, many based on little empirical evidence, and placed the onus for countering fatigue solely on the driver (Haworth & Herffernan 1989). Formal programmes for fatigue management are considered to have begun in 1994 when the first recognised comprehensive scheme was developed and piloted by Queensland Transport in Australia (Knipling 1998). Queensland Transport saw fatigue as a growing safety risk, and one which the existing traditional hours of work legislation was unable to address (Feyer et al. 2001, Nolan 2005). They therefore devoted considerable resource to changing the way fatigue is managed by its transport companies. Participating fleets were granted relief from prescriptive hours of service legislation in return for implementing a comprehensive programme to prevent fatigue through informed scheduling, driver and manager training, and driver screening. For Queensland Transport, the FMP was "*a performance-based approach to managing fatigue that places the onus on the [company] to take responsibility for and manage the fatigue of their drivers*" (Mahon 1998). Thus for the first time, the focus of responsibility for fatigue risk, and with it the motivation to control fatigue risk, was shifted from the government to individual organisations. Several commentators saw this formal FMP approach as an improvement on higher level prescriptive legislation because it was designed to identify and tackle *all* factors that cause and increase the risk of fatigue, not just hours of service.

Since this time there has been definite growth in fatigue risk management by transport companies (an account is given by Phillips & Sagberg (2010)). Regulatory frameworks in some countries and sectors have also developed from those based on hours of work to promotion of fatigue risk management systems (Gander et al. 2011). Today it is generally recognised that managing fatigue in real-world contexts requires that the fatigue in question is understood, that individual differences in fatigue vulnerability are appreciated, and that organisations are willing and able to select and implement those evidence-based countermeasures that are best suited to their operations (Caldwell et al. 2008). In line with this, national and international transport authorities (especially in air, maritime and rail transport), are increasingly issuing guidelines and/or legislation on fatigue risk management. The UK rail regulator, Transport Canada, The US National Transportation Safety Board, the International Maritime Organisation, the European Aviation Safety Authority and the US Federal Aviation Authority have each made formal moves of varying degrees towards fatigue risk management by organisations (Fourie et al. 2010). There are, however, large differences in guideline implementation among transport sectors. Summarising international findings on fatigue management by road transport companies, Phillips & Sagberg (2010) found that:

- Many companies (especially smaller ones) have no formal fatigue management policy and what policy there is often outlines hours of work regulations and/or is inconsistent with the management of fatigue.
- Policies are often communicated only verbally to the drivers.
- Most companies do not provide any fatigue management training to drivers.
- There is too little skill or little or no knowledge of circadian principles among those producing rosters.
- Driver knowledge is more in line with contemporary knowledge on fatigue risks than is management knowledge.

Indeed current policy governing all road transport companies in wider Europe still aims mainly to delineate approved shift pattern standards and durations, and to check organisational rosters against these standards for any unapproved patterns. Although this approach is now more grounded in evidence on fatigue-influencing factors than traditional hours of work approaches, it still fails to account for many work-related influences on operator fatigue. In stark contrast, safety management systems are now required for operators in all elements of the global aviation system (ICAO 2013).

Phillips & Sagberg (2010) identify several potential advantages of fatigue risk management for transport companies. One of the biggest advantages is operational flexibility. The reality for many road transport organisations is that delivery times at outlets or depots can often fail to sufficiently account for driving and resting time rules, but at the same time are experienced by the drivers as non-negotiable. This is especially the case in long-distance transport (Nolan 2005). In the transport of perishable goods in particular, scheduling needs to be reactive not only to seasonal demands, but to daily price fluctuations, which lead to varying requirements of customers who act in fiercely competitive environments. Given such challenges, organisational interventions that educate drivers and managers and allow for flexible but safe scheduling are promising ways forward. Management of fatigue at the organisational level has the potential to allow the monitoring and accounting for factors such as trip preparation, quality and quantity of rest, cumulative effects, circadian rhythms, individual differences, unforeseen factors and day-to-day variations (Moore 1998). An integrated programme that addresses the requirements of different groups in an operation increases the chance that fatigue countermeasures will succeed (McCallum et al. 2003).

2.8 Fatigue Risk Management Systems (FRMS)

Phillips & Sagberg (2010) found that the most common countermeasures employed in fatigue management programs across different sectors were:

- Training
- Schedule management
- Sleep disorder screening and treatment

Few companies implemented the following measures as part of fatigue management:

- Fitness for duty monitoring
- Employee incentives
- Promotion of open reporting culture
- Competency-based recruitment

Moreover, it was found that organisations wishing to tackle fatigue often select one-off countermeasures – typically one-off training (Phillips & Sagberg 2010). In addition, since managers did not integrate these measures into formal and informal aspects of business management, employees perceived lack of management prioritisation of the problem, and managers failed to evaluate or follow up any problems. That the cultural dynamics of the organisation can undermine the prioritisation of fatigue is supported by theory on organisational culture (Schein 2004). One way to address these issues is to apply fatigue countermeasures in the context of a safety management systems (SMS).

SMS are increasingly implemented by businesses wishing to balance safety, productivity and costs. Approaches to SMS recognise that workplaces are complex, dynamic systems and that the causes of safety-related incidents can arise from a broad range of interacting factors from all levels of the organisation and outside of the organisation (Williamson & Friswell 2013). To produce safest outcomes there is therefore a need to address whole systems of risk factors. Lerman et al. (2012) describs six elements of an SMS (Table 2).

Table 2. Elements of a safety risk management system (SMS) and fatigue risk management system (FRMS), based on Lerman et al (2012).

	SMS	FRMS
1	Safety management policy	Fatigue management policy
2	Risk management	Fatigue risk management
3	Reporting	Fatigue reporting systems for operators
4	Incident investigation	Fatigue incident investigation
5	Training and education	Fatigue management, staff and family training
6	Internal and external auditing	Continuous monitoring of effects of FRMS

Importantly, when incorporated into a modern SMS, each element is linked to a formal structure involving people and resources aimed at achieving safety. In addition to formal elements and their organisation, informal processes will be important, as they are in any organisational context. In particular, an informed, just and open reporting culture will be important to the success of the SMS (Reason 1998).

The risk management process is the core element of any SMS. Risk management is identification and control, through monitoring and containment, of hazards that threaten people in organisations (Williamson and Friswell, 2013)[1]. When the risk managed by an SMS is that from the hazard fatigue, the system is denoted a fatigue risk management system (FRMS), and six elements can be described with parallels to general SMS (Table 2). FRMS has been defined as (IATA/ICAO/IFALPA 2015):

"*A data-driven means of continuously monitoring and managing fatigue-related safety risks, based upon scientific principles and knowledge as well as operational experience that aims to ensure relevant personnel are performing at adequate levels of alertness.*"

ICAO guidance structures the required components of an FRMS, each coordinated by a fatigue action group (IATA/ICAO/IFALPA 2015):

- policy (identifies FRMS elements, operations, reflects shared responsibility, states safety aims)
- documentation (of policy, procedures, mechanism of stakeholder involvement, training records, planned and actual schedules, outputs)
- risk management processes (hazard identification, risk assessment and mitigation)
- safety assurance (monitoring of FRMS performance, managing change, continuous learning)
- promotion processes (training program and communication)

According to Moore-Ede (2010), FRMS is:

- evidence-based
- driven by collected data
- run by collaboration of all involved stakeholders
- system-wide, with respect to use of tools, policies and procedures
- integrated with other organisational systems e.g. human resource, occupational health
- budgeted and based on business case
- bought into at all levels
- subject to continuous improvement
- all stakeholders share responsibility for complying with and improving FRMS

Operationally, FRMS may also be viewed from a prevention, prediction, detection and intervention perspective (CASA 2014).

According to Belenky (2011), FRMS operates on a principle of iterative improvement dubbed test, operate, test, exit. For FRMS, test involves monitoring of added or embedded measures of performance, together with observation of error, incident or accident and/or loss of productivity and making absolute or relative comparisons to previous performance or some other standard, and thus detecting drift. "Operate" involves changing something in the system (e.g. schedule), and then "test" involves observing the effect of the intervention. The process is reiterated until the desired

[1] A hazard is a factor with potential to cause harm and risk is probability of a hazard occurring and of the consequences of the hazard occurring.

result is achieved, although the system will still be monitored. Thus error, incident and accident analysis is key to FRMS. Importantly, FRMS can be implemented in a variety of forms, from the technologically simple to the technologically complex, and organisations of any size may benefit from them (Belenky & Åkerstedt 2011).

In reality, many transport companies – especially smaller organisations in the maritime or road transport sector – still have no formal SMS or FRMS (Phillips 2014). Some will no doubt attempt risk management in isolation or as part of their occupational safety and health efforts. Indeed, Williamson & Friswell (2013) argue that since it is most in line with existing legislation, companies will be more motivated to manage fatigue in line with traditional health and safety approaches to risk management, where a hierarchy of hazard control levels should be considered. Using such an approach, the safety manager should attempt the following:

1. Eliminate the causes of fatigue from the workplace.
2. Reduce exposure to causes of fatigue in the workplace.
3. Implement work-related controls to reduce the effects of performance degradation due to fatigue.
4. Monitor and control employee exposure to fatigue risk.
5. Reduce the individual's fatigue risk.

However, these approaches will be suboptimal where the risk management process is not anchored into and supported by formal and informal aspects of the organisation. It seems therefore that improved solutions are required for transport companies with more limited resources, to provide a simplified and pragmatic approach to SMS/FRMS.

2.9 Selection of countermeasures in fatigue risk management

There are several important questions to be asked when selecting countermeasures for fatigue.

1. What is the undesirable fatigue-related event that we wish to prevent (e.g. safety- or health-related?)
2. What sort of fatigue leads to this event (Rose & Giray 2013)?
3. What factors influence this fatigue?
4. Which countermeasures can be used by the organisation to manipulate these factors, given available resources?
5. Is there evidence that the countermeasure selected reduces fatigue by manipulating the fatigue-influencing factors (FIFs)?
6. How can the effects of the countermeasure on FIFs, fatigue and fatigue outcomes be measured?
7. What are the criteria for success?

To begin with an undesirable incident must be selected for analysis (question 1. and 2.). This may be an obvious problem, such as a high frequency of sleep-related accidents among employees. However, in some cases any negative effects of fatigue on employees and their health and performance may be less obvious, in which case prevalence can be analysed. Alternatively the organisation may be concerned about an increase in sickness absence or turnover, which may be partly due to increased fatigue.

Because FIFs span work and non-work life, the entire workforce may be enlisted as active partners when answering question 3. These consultations may also form the basis of participative interventions, in which employees identify problems and influencing factors and design solutions may help (Nielsen 2014). Employee participation is also in line with claims that individual factors and preferences must be incorporated into any fatigue management plan (Rose & Giray 2013). The manager will also need to consider organisational resources when selecting appropriate countermeasures. A small transport company employing three employees operating in a competitive branch may not be able to implement a comprehensive fatigue risk management system in order to address operator sleepiness, but they may still be able to focus on key measures, such as driver education, sleep monitoring or health and safety culture.

Investigations into the most important FIFs – using research knowledge, the above employee consultation, and knowledge of system constraints (e.g. resources) – can be facilitated by Reason's hazard control framework, in which accidents are the end result of a longer chain of events and not merely those "frontline" factors apparent at the time of the incident (Reason 1997). In this model safety is compromised when a hazard – in this case fatigue – is able to penetrate several barriers of defence, due to active failures in the system (Reason 1997). Using this model Moore-Ede (2010) identify five key defences of a FRMS, which describes metrics and actions to be used towards achieving five defence goals. This in turn is in fact based on an interpretation of Reason's model by Dawson & McCulloch (2005) where the level of fatigue risk determines the information to be monitored to help decide whether controls are needed. This model is known as the fatigue risk trajectory, reflecting Reason's original thinking. We have previously presented a version of this model modified slightly to account for a broader operationalization of fatigue (Phillips et al. 2015). This model is given in Figure 1.

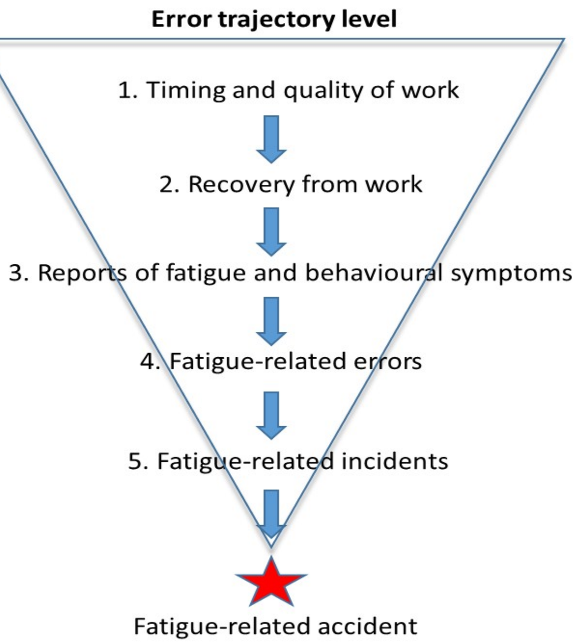


Figure 1. Dawson & McCulloch (2005)'s fatigue risk trajectory modified to account for a broader definition of fatigue. There are several layers preceding a fatigue accident that must be penetrated by active failures in the system. Effective FRMS requires that the risks in each layer are controlled by effective countermeasures. The original model dealt with sleep-related fatigue.

The model describes a series of defence levels, where each level describes a threat to safety that must be managed in order to control the fatigue hazard. Thus attempts can be made to prevent fatigue by arranging work schedules that allow sufficient time for recuperation and designing jobs that are not so fatiguing that the operator cannot recover from them (Level 1). Even where fatigue is controlled by the timing and quality of work, there may be periods of unusually fatiguing work, or individuals may not be able to (or may not want to) obtain sufficient sleep and rest during their free time in order to recover from work (Level 2). In cases where people who have not recovered fully have to work, or where people become fatigued during work despite prior attempts at control, there must be countermeasures that detect signs of fatigue at work and limit its effects (Level 3). Where fatigue-related errors still occur, they must be captured and dealt with, even when they do not result in an incident (Level 4). Finally any fatigue-related incidents that still occur (e.g. truck driver exits lane temporarily; train driver misses a signal) must be reported and learnt from in order to prevent similar incidents or accidents.

Fatigue-reduction strategies, which reduce the likelihood that a fatigued individual is operating, correspond to level 1 and 2 of the FRMS. Workplace fatigue can also be reduced by excluding operators from the workplace who are not sufficiently rested (level 2). Dawson et al. (2012) distinguish between fatigue-reduction strategies and fatigue-proofing strategies, which decrease the chance that a fatigued person operating in the workplace will make an error that leads to an incident or accident. Fatigue-proofing applies more to level 3 and 4.

The fatigue risk trajectory is a very useful tool to help structure the selection of countermeasures in fatigue risk management, by implying that barriers need to be put in place to prevent fatigue developing at each of the hazard levels depicted. So, for example, schedules could be analysed for fatigue risks using biomathematical software to control the most important fatigue risks at level 1, if schedule timing was the main risk identified, while surveying recovery from work before the start of the next shift could be implemented at level 2, and so on. The idea is that countermeasures are implemented and fatigue indicators monitored at each risk level in order to properly manage fatigue risks. In this report, we will use the fatigue risk trajectory to classify the countermeasures as we review them. Structuring countermeasures like this will be useful for the fatigue risk manager, whatever the type of transport branch or organisation they work in.

3 Review of available countermeasures

3.1 Aim of the review

The main question to be addressed by this report is which individual countermeasures should different types of transport organisation wishing to tackle fatigue consider? Schedule managers, line managers and business owners are faced by a complex array of possibilities, complicated still further by the rapid developments in technology, such as wearables. A timely review of available countermeasures and their effectiveness might help. In particular, insufficient attention has been paid to the reality of many transport operations as small, independent outfits with limited resources. This is especially so in the goods transport by road and sea, and in the rail sector there may be small private cargo operations or even independent owner drivers.

The aims of this report are to:

- identify main countermeasures to fatigue by reviewing the literature from the last 20 years
- classify the countermeasures according to (a) the fatigue-inducing factors (FIFs) addressed and (b) where the FIF is located along a fatigue risk trajectory
- review any knowledge on effectiveness
- assess which countermeasures may be best suited to which types of transport operation
- assess systemic fatigue countermeasures
- identify future research needs

The report does not consider the following:

- countermeasures still in development e.g. HRV neural network analysis
- more "unethical" countermeasures e.g. stimulant drug use
- adjustments to hours of work regulations
- publicity campaigns

3.2 Method

Existing knowledge on countermeasures available in the peer-reviewed scientific literature was gathered in the following way: The search terms "fatigue" + "countermeasure" + ["transport" or "driver" or "human operator" or "pilot" or "watchkeeper" or "bridge officer"] were entered into the following search databases for the years from and including 1996 up to and including 2015:

- Science Direct
- TRID database combining posts from Transport Research Board's and

- OECD's international transport research documentation.

The article titles were reviewed, and articles not directly dealing with countermeasures were discarded, e.g. we did not include reviews of the psychophysiology of driver fatigue.

Knowledge of countermeasures from the peer-reviewed literature was supplemented by content on other commercially available countermeasures performing a Goolge search using the words "fatigue countermeasures transport". The first ten pages of "hits" were reviewed. We also reviewed reports that were known to us from previous work on an ERA-NET project on driver fatigue (Wilschut & Caljouw 2009, Phillips & Sagberg 2010) and a Swedish workshop on countermeasures for fatigue in transport (Anund et al. 2015).

In this way, we identified 95 key references dealing with fatigue countermeasures in land- and sea-based transport. (These are indicated with "*" in the Reference section). These key references were supplemented with references giving background information available from the author's existing database.

3.3 Results

To present the results of our review, the countermeasures are grouped according to which of the five levels of the fatigue risk trajectory (shown in Figure 1) the fatigue hazard dealt with should be placed. We begin with countermeasures dealing with fatigue hazards at level 1, which concerns fatigue caused by the timing and quality of work. We then present countermeasures dealing with fatigue hazards at level 2, which concerns whether there is sufficient recovery from fatiguing work, and so on.

3.3.1 Level 1. Timing and quality of work

Timing of work

Work timing can produce acute fatigue in the operator where high levels of exertion are required to work through circadian dips. It can also cause chronic problems e.g. working a large number of hours, irregular shifts or shifts at unusual times of the day over longer periods (Lie et al. 2014). The timing and quality of work influence not only the levels of exertion, but also the opportunity for sleep and recovery from that exertion. Therefore the timing of work is of ultimate importance for transport operator fatigue[2].

Countermeasure 1. Adequate manning

According to Moore-Ede's model of defences-in-depth against fatigue-related accidents, adequate manning is the first level of defence in fatigue management, not least since it determines how work is distributed among the employees, both in terms of time and task intensity (Moore-Ede 2010). According to Moore-Ede it is the most important determinant of overtime, time off between shifts, working hours per shift and week, and the discrepancy between planned and actual schedules worked.

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[2] In the search for latent errors in the system, one may go further back and look at organisational and sectoral conditions that influence the timing and quality of work, but this is beyond the scope of this report.

Lerman et al. (2012) review the various FIFs linked to inadequate manning in the workplace, and arrive at similar conclusions. In summary, inadequate manning can lead to an unduly high workload and overtime, and can worsen the fatigue effects of shift work. In order to provide necessary cover, the workforce may have also to come in at short notice, and shifts may be more unpredictable and irregular. Operations that are minimally manned are more vulnerable to increased workload and overtime during employee absences, and this can also worsen problems with shift work.

Reduced manning as a result of increased automation in the maritime sector seems to have left crew more exposed to fatigue during busy phases of an operation, since there are less crew to help out. In particular there are less people on the bridge to look out for the signs of fatigue amongst others, who may be increasingly fatigued in the role of passive monitor of instrumentation (Lützhöft et al. 2011). Manning levels have been directly linked to fatigue risks in the maritime sector (Akhtar & Utne 2015).

All transport sectors face challenges in manning sufficiently for varying demands associated with different phases of a transport operation. For instance, seafarers may have to exceed working hours regulations during port calls, or drivers may feel it necessary to help load or unload to prevent delays at terminals, even though it is not officially their duty (Lützhöft et al. 2007, Phillips et al. 2015).

Manning levels are often kept at a minimum in order to maximise productivity, so an obvious concern for transport managers will be the perceived costs of providing extra manning as a fatigue countermeasure in terms of recruitment, wages, insurance and pensions. Some authors challenge the assumption that the costs of extra manning outweigh the advantages of reducing fatigue, and state that extra manning as a countermeasure may best be implemented by first convincing senior managers about the hidden health and safety costs of minimal manning (Lerman et al. 2012).

Not all manning problems are linked to productivity needs. In addition to unplanned sickness absence, reduced manning can also be caused by predictable factors such as holidays, training or time taken to recruit replacement operators. The varying manning demands of different operational phases can also be predicted to some extent. The implication is that there may be room for managers to plan better to ensure manning levels are adequate in order to reduce fatigue.

According to Lerman et al. (2012), providing adequate manning should involve:

- Re-examining and reengineering processes to reduce the number of employee positions that are needed to be filled per shift.
- Cross-training employees so that a greater pool of employees is available from which to fill positions.
- Introducing proportional staffing according to predictable operational fluctuations.

Countermeasure 2. Schedule design

When employers create a schedule, they effectively determine three important influences on fatigue: opportunity for sleep, time of day the operation is performed and the length of time spent on the operating task and at work. Scheduling work and rest to account for fatigue is in most cases the most direct way managers can influence how fatigued their operators become. This is reflected in the fact that 80 % of attempts at fatigue management by transport organisations reviewed by Phillips &

Sagberg (2010) involved attempts at improved scheduling and rostering. Moreover, almost all guidelines issued by regulatory authorities detail the need for scheduling to account for fatigue causes.

Society's demands for round-the-clock transport are such that transport managers must ask operators to work outside the hours of 07:00 h and 18:00 h and in many cases to work shifts or watches. Having to work at "unphysiological" times of the day when one would otherwise be asleep can cause acute fatigue due to circadian lows, but it also causes fatigue because it is notoriously difficult to obtain sufficient sleep prior to such work. The latter is particularly true of night work and early starts. For instance, a study by Roach et al. (2012) on short-haul airline pilots suggests that 15 minutes of sleep is lost for every hour a shift starts before 0900 h, which is also reflected by studies on train drivers (Phillips 2014). Work at unusual times also affects quality of life of the individual, and in particular social interactions or work-life balance. After many years of exposure to work at unusual times of day, health and safety may be affected (Wright Jr et al. 2013).

Whether or not work is conducted at unusual times of the day, fatigue can be caused if there has been a long time since the last sleep bout (sleep homeostasis), build-up of sleep debt due to recent work patterns, or if the work or task has been conducted for several hours or more. Research suggests that less than 5 h sleep or more than 16 h of wakefulness in the 24 h prior to work can significantly increase the likelihood of fatigue-related impairment and error at work (Dorrian et al. 2011). Naturalistic driving studies have also shown exponential safety declines with time on shift, with roughly double the likelihood of accident or injury after 10 h relative to the first 8 h (Hanowski et al. 2007, 2009).

Phillips (2014) summarises the many studies examining the effects of shift work and schedules on fatigue. Some of the main findings are:

- in the maritime sector, studies comparing different watch systems conclude that two-watch[3] 6-on/6-off arrangements cause more fatigue than three-watch systems, but there are economic, operational and cultural reasons why both crew and employers may favour traditional 6-6 watch systems.
- night shifts and early starts have been found to cause more fatigue than day or late shifts in the rail sector.

Also concluding for the maritime sector, Smith (2006) claims that improvements can often be achieved replacing the two-shift with a three-shift system (requires more manning) and/ or introducing more flexible shift system with a minimum 8 hour rest period.

To counter the effects of demanding work times, Boivin (2000) recommend that schedulers of professional truck drivers should:

- aim to limit night driving, especially between midnight and 6 am
- limit the number of night trips to a succession of two or three nights
- give at least two full nights' sleep after an extended driving period
- design work schedules around circadian patterns
- avoid 12 h shifts

[3] Two "watches" or crew groups cover 24 hours by taking turns to rest and work e.g. the first group works 6 hours (on) and then rests for 6 hours (off) while the seconds group rests for 6 hours and then works for 6 hours.

- preserve minimum 9 h rest periods between shifts, and minimum break periods within shifts
- rotate drivers between long-haul driving and base duties, in order to account for the need for drivers to sleep at home.

Evaluations of schedule interventions in transport are somewhat hard to come by. A systematic review of studies summarized the following schedule interventions were found to have beneficial effects on health for general workers (Neil-Sztramko et al. 2004):

1. Switching from slow to fast rotation (e.g. rotate shift type every 3-4 days instead of every 6-7 days).
2. Changing from backward to forward rotation.
3. Self-scheduling of shifts.

These improvements can sometimes be made with little or no cost to the organization.

Several tools are now available to help predict fatigue risks for given work schedules. These can vary in complexity from Åkerstedt's (2010) tool based on a simple formula allows drivers to predict their own fatigue when and where they want to, through to whole crew management solutions centred on web-based software that can be linked to an organisation's existing scheduling software to analyse planned or actual schedules worked. In an example of the latter, Continental Airlines' combine scheduling software with other programme elements to form a central component in a fatigue risk management approach centered on scheduling improvements (Gunther 2008). Data is collected from surveys, actigraphs and diaries, and used alongside predictive software to inform continuous evolvement of schedules and rosters.

All tools are based on biomathematical models of human fatigue, allowing schedulers to incorporate aspects of fatigue science into scheduling through prediction of fatigue risk levels, performance or safety levels or sleep times (CASA 2010). The models are based on what we know about sleep drives, that can help predict sleep need and performance, given a certain sleep history. According to Williamson & Friswell (2013) these are being used by some transport organisations, although more evidence is needed about the ability of such software to reduce the likelihood of fatigue occurring.

CASA (2014) review seven biomathematical models that are (i) available for use in schedule assessment and (ii) supported by peer review papers. The reviewed models were found to have the following applications:

- design of schedules to minimise fatigue
- minimise fatigue effects of irregular operations
- evaluation of countermeasures, such as napping or alteration in sleep timing
- basis of software or smartphone apps for individual fatigue prediction
- illustrate effects of sleep on fatigue during training
- analyse the role of fatigue during accident/incident investigations

The models also varied according to whether they:

- were based on a 2- or 3-process model of sleep
- accounted for the task performed
- were based on actual sleep-wake data or work-rest patterns

They also varied according to the output variable. Some predicted a fatigue value over a work period in relation to subjective scales, such as the Karolinska (Åkerstedt & Gillberg 1990) or Samn-Perelli scales (Samn & Perelli 1982), while others gave relative fatigue risk scores.

Despite much progress, several limitations remain for biomathematical models on which schedule analysis software are based (Booth-Bourdeau et al. 2005, Dawson, et al. 2010, 2011). These are that they:

- underestimate fatigue from chronic partial sleep deprivation.
- make fatigue risk estimates at group level, i.e. the considerable variation in fatigue vulnerability within and between individuals is not accounted for. The models should not be used to justify schedules that may be too challenging for some individuals.
- account for an incomplete set of fatigue-inducing factors, not only related to variation among individual operators, but variation in operational phase, workload variability or traffic volumes.
- have not been validated in the context of specific transport branches.
- have been tested and validated mostly using data on actual sleep/wake periods, despite the fact that schedulers often only have information on work schedules.
- are good as predictors of safety risks due to fatigue that are due to homeostatic drives, but not so good at predicting those due to circadian drives.
- say little about acceptable levels of fatigue.
- do not predict chronic effects of fatigue evidenced by:
  - the chronic impact of work schedules or on intermittent partial sleep restriction on performance capabilities; and
  - the risk of occupational injuries to shift workers on rotating systems, relative to day workers (Horrey et al. 2011).

The second point in the list above may be the most important. According to Darwent et al. (2015), robust variability in the amount of sleep obtained by drivers indicate that models are relatively poor tools for ensuring that all employees obtain sufficient sleep. These findings demonstrate the importance of developing approaches for managing the sleep behaviour of individual employees, and the need to some measure of how much sleep individual operators actually get.

An additional problem with the use of fatigue risk scores generated by software programs arises from the need to define risk limits for a schedule (Dawson et al. 2011). In companies with a prescriptive culture, these limits may simply replace hours of sleep regulation limits. In other words, a pro-active, flexible and informed approach to fatigue management may not occur if scheduling software is the only element in an FMP, and there may therefore be no benefits over traditional approaches to fatigue management.

A further problem for these models is that the safety risk for a given level of fatigue will vary according to type and context of safety behaviour (CASA 2014). However, SAFTE-FAST has been developed to predict fatigue-induced cognitive decrements based on the psychometric vigilance test (PVT) (Roma et al, 2012, in CASA, 2014). An alternative approach made by the HSEs Fatigue Risk Index is to estimate the risk of an accident or injury occurring during a particular shift, relative to the risk for a given shift pattern (Folkard et al. 2007).

Despite the above reservations, there is much the organisation can do to limit fatigue in its employees by optimal planning of schedules using biomathematical models, and there is often a legal obligation to assess fatigue risks imposed by schedules (Houtman et al. 2005). Moreover, there are several indications that accounting for fatigue in scheduling leads to positive changes. For example,

- a schedule change carried out in a shipping organisation aiming to increase sleep opportunity in exchange for extended working periods was positively received by the crew, with a decrease in the number of near miss incidents (Gertler et al. 2002).
- software analysis and schedule development by a company with 500 trucks resulted in a fall in traffic accidents of 55 % in the course of a year (Moore-Ede et al. 2004).
- an account for scheduling of engine drivers resulted in reduced subjective ratings of fatigue (McCallum et al. 2003).
- an attempt to adjust schedules based on software-generated fatigue risk scores resulted in an increase in sleep opportunity (Dawson et al. 2010).
- A fatigue risk assessments of train driver rosters in Ireland, UK, Australia and South Africa showed not only that the existing roster designs increased fatigue risk, but that operations were protected (McColgan & Nash 2009).

There are claims from these and other pilot studies that practicality and functionality of roster redesign based on modelling has been demonstrated. The models are useful as ways to compare schedules for fatigue risks in order to select optimal schedules for the average operator as part of a multi-layered FRMS, but scheduling managers must be careful not to over interpret fatigue risks estimated by models, especially by making inferences about actual sleep from mere scheduled sleep opportunities (Dawson et al. 2010). The tools should never be used to predict absolute fatigue levels, nor as the sole means of designing or justifying schedules.

Countermeasure 3. Timing of breaks and naps

Fatigue as a result of time-on-task has been shown to be relieved by breaks within shift (Belenky & Åkerstedt 2011). Inclusion of a rest stop while driving is known to help reduce fatigue-related crashes (Reyner et al. 2006). The challenge for the manager may be not only in conveying sufficient breaks are scheduled for their operators, but that operational pressures do not curtail these breaks, and that drivers perceive that they can take the scheduled breaks despite delays etc.

In practice work timings and demands vary widely from day to day in several transport sectors, and the number and timings of breaks may need to vary also. There is little knowledge about the extent to which this is possible within the confines of legislation. The need for more or less breaks may be informed by other aspects of the FRMS, since task performance is influenced not only by workload but time of day and sleep history. Thus warnings on the need to take a break based on time on task may be overly simplistic.

Another point is that the aspects of the task environment that are fatiguing can continue on during breaks. On ships especially, vibration, noise and motion may be difficult to get away from (Calhoun & Lamb 1999). On a psychological level there may be work-related telephone calls or other interruptions.

The timings and lengths of break timings are dealt with by several reviews (Caldwell 2001, Jay et al. 2015), but more should be done to assess the evidence on self-elected break times and compatibility with driving and resting time regulations.

In a study by Gershon et al. (2011), planning ahead was found to be an important tactic used by professional drivers to counteract fatigue, e.g. checking location of desirable rest stops along the away. The organisation could encourage and support such behaviours as part of its fatigue risk management.

Countermeasure 4. Accounting for actual hours worked

Managers should realise that there can be large differences between schedules that are planned to reduce fatigue risks and those that are actually worked. In some cases managers may wish to fulfil employee wishes to swap schedules in order to maximize free periods or to work overtime, but many of these changes occur at the last minute and the effects on fatigue are often not accounted for (Phillips et al. 2015). In addition to recording actual working patterns, employers should therefore assess the fatigue effects of late alterations to the schedule on fatigue risks, and perform comparative analyses of the fatigue risks associated with planned versus actual schedules worked to estimate whether the discrepancy is large and needs to be addressed in cooperation with employees (Office of Rail Regulation 2012). Whether scheduled breaks are taken should also be analysed by comparing planned and actual working times.

Quality of work

There is a considerable variation in the tasks that different transport operators are asked to do. Long spells of soporific monotony may often be experienced by operators like long distance truck drivers, international oil tanker officers or intercity train drivers, while physical challenges may be greater for urban truck drivers or taxi drivers (regular loading or unloading), or officers on smaller fishing vessels (Phillips et al. 2015).

When accounting for the different effects of work quality on fatigue, it is useful to consider auxiliary tasks alongside the main operator task. The following are examples of auxiliary tasks may influence how fatigued different operators are when they are carrying out the main operating task, based on a job content analysis in Norwegian operators by Phillips et al. (2015):

- 43 % of offshore service officers and captains spend over 40 % of the time on paperwork and administrative tasks.
- 23 % of officers and captains on fishing vessels spend over 20% of their time on physical tasks.
- 39 % of taxi driver owners spend over 40 % of their time waiting for jobs.
- 59 % of goods drivers (road) spend over 20 % of their time on physical tasks.
- Auxiliary tasks are less dominant for train drivers, but a considerable share spend their time waiting between assignments.

A study by Tzamalouka et al. (2005) gives evidence of the importance of considering auxiliary tasks, showing that for freight transport operators, non-driving hours of work and type of cargo transported were powerful predictors of falling asleep behind the wheel and crash probability, in addition to hours of sleep. An early study by Mackie and Miller (1978) supported that loading duties increased the severity of fatigue imposed by work schedules. Some naturalistic studies on truck drivers find that time spent on other duties before driving can substantially increase accident risks towards the end of a drive (Soccolich et al. 2013), while others studies imply that loading can be arousing (Hanowski et al. 2003).

Countermeasure 5. Optimise job content and work environment

To address the above problems a task and work environment analysis should be performed as the basis of mitigating actions to minimise the extent to which:

(i) the main operating task is fatiguing (taking account of the role of factors such as lone working, automation and timing) and

(ii) auxiliary tasks increase the chance that fatigue occurs during the main operating task or that sleep is affected.

Regarding (i), increased automation is a potential source of increased fatigue for transport operators, who are increasingly becoming passive observers of the system (increasing automation of bridge at sea and of the train/truck driver task). On the other hand, automation can be beneficial if it reduces the workload of the driver whose fatigue is due to overload (May & Baldwin 2009). Managers could seek to use increasingly available adaptive automation solutions that aim to reduce task load at times when operator performance is most susceptible to fatigue risks, e.g. by giving audible instead of visual messages if the driver is visually overloaded. If underload is the problem, the driver may be given secondary tasks to perform e.g. cancelling of an auditory alarms or other secondary tasks (Gershon et al. 2009, Verwey & Zaidel 1999, Oran-Gilad et al. 2008). More research is needed in this area to assess problems related to distraction, and the longer term effects of secondary tasks, and there are practical issues related to field use. A particular challenge is being able to distinguish different sorts of fatigue from each other in a valid way when they are detected. This is important because increased automation in a driver who is fatigued because of monotonous task conditions, for example, would be dangerous. Moreover, such solutions are only relevant for task-related fatigue and cannot be applied for sleep-related fatigue (May & Baldwin 2009). This field is continuously developing and manufacturers may have more advanced technical solutions to reducing the fatiguing nature of the operator task than our literature search has revealed.

Regarding (ii), above, we wish to make two points. First, managers should ask how does non-operating work, such as delivery deadlines, waiting, off-duty time, driving round looking for assignments, queuing, loading, paperwork, customer engagement and so on, curb sleep, and how does it affect the likelihood that the operator will be fatigued while operating (Phillips et al. 2015)? Furthermore, what is the nature of the non-operating work? Does it lead to stress and exacerbate fatigue or does it provide welcome variation in the operator's working day? Is there work outside of the official schedule that limits sleep opportunities and the ability to disconnect? A consideration of the demands of secondary tasks and the psychological (e.g. available support from colleagues and leaders) and physical (e.g. functioning equipment for vehicle safety checks) resources available to deal with them is important.

Second, different tasks performed can be plotted over time to reveal periods in which the operator will be particularly susceptible to fatigue risks, such that mitigating actions can be applied to risky periods. For example, there may be a need for extra vigilance for those working the first bridge watch immediately following a busy port call, who have not yet had a chance to recuperate.

Job content analyses may be usefully supplemented by subjective workload profiles, as reported by the operators themselves, for instance using the NASA Task Load Index (Friswell & Williamson, 2008). The extent to which truck drivers, for example, experience physical demands as fatiguing is important information to supplement knowledge that they spend considerable time on physical tasks. Time pressure, frustrations and emotional demands of the job should also be considered as fatiguing for some operator roles (e.g. urban bus drivers). In addition, there may be environmental sources of fatigue to consider. For instance, Phillips et al. (2015) found that cargo train operators reported being subject to substantially higher levels of noise and vibration than other transport operators.

The aim of these analyses is always to identify mitigating actions that can limit the build-up of fatigue over the shorter or longer term, e.g. by adding a crew member to take over officer's administrative tasks at sea (Houtman et al. 2005). In reality there is considerable variation in the extent to which these and other human factors analyses are conducted in different branches, and they have been especially overlooked in professional road transport (Calhoun & Lamb 1999). In many branches, operational phase, productivity needs and manning levels are still the main determinants of the which tasks are carried out when and by whom.

3.3.2 Level 2. Recovery from work

The most effective fatigue countermeasure in all transport settings is to eliminate it by taking sufficient rest and sleep sufficiently often. Fatigue occurs when this is not possible. Recognising this, rules on working and operating times stipulate minimum main rest periods, and researchers continue to recommend extending rest periods as the main way to tackle fatigue (Houtman et al. 2005). The problem is that just because one is given the opportunity to rest or sleep, does not mean one actually does it, and operators are often in life situations that are not conducive to recovery e.g. need to commute long distances, busy social life, need to care for family. Thus it seems that transport companies should analyse whether transport operators have actually recovered sufficiently from previous work during the rest time given, before embarking on a new work period. There are several ways in which this can be done.

Countermeasure 6. Accounting for actual sleep obtained

No countermeasure for sleepiness while operating is as effective as sufficient sleep aligned with circadian rhythms (MacLean et al. 2003). The most accurate and reliable way to measure sleep quantity and quality is with relatively invasive techniques like polysomnography (brain wave measurements), but traditionally this has been difficult to apply in the field due to the need for electrode arrays (Belenky et al. 2011). Technology is becoming available that can be used for occasional measurements as part of FRMS (SmartCap), but is still less practical than actigraphs.

An actigraph is a wrist-worn device containing an accelerometer, signal processing hardware and software, and memory. Actigraphy is cheaper and less obtrusive than polysomnography, gives comparable measures of total sleep time and sleep efficiency, and can record sleep history over the past few weeks (Belenky et al. 2011, IATA/ICAO/IFALPA 2015). Recent years have also witnessed the rapid emergence of wearables, which allow for monitoring of individual work and sleep patterns in a similar way (CASA 2014). Apps are available that use the mobile phone's accelerometer to collect data on sleep quality and quantity (Hao et al. 2013). Data on sleep recorded by actigraphs, wearables or phones can be input into schedule analysis software to help predict fatigue risks and alter schedules accordingly. Field validation in the use of actigraphs to give schedulers feedback as part of FRMS is being pioneered by companies like Fatigue Science. Data from actigraphs will in most cases need to be aggregated at group level before analysis by managers, and corporate packages are available from wearable manufacturers with which to do this. Actigraphs can also be used to help evaluate company interventions aiming to improve driver sleep.

Individual feedback and tips about how to improve sleep hygiene may in addition be given to drivers based on their own data, using wearables from manufacturers like Jawbone, FitBit or Garmin. More comprehensive solutions that are tailor made for transport operators are also available from companies like Fatigue Science.

Paper-, mobile- or tablet-based sleep logs filled out by the operators themselves may also be used to supplement or replace objective data, and are cheaper than objective forms of sleep monitoring. However self-estimations of sleep duration and efficiency (how long it takes to fall asleep) can be unreliable (IATA/ICAO/IFALPA 2015).

Countermeasure 7. Health screening and treatment

Sleep disorders or health conditions influence how long and well the employee sleeps, and therefore how well they recover from work-induced fatigue. There is compelling evidence for the effect of primary sleep disorders (insomnia, obstructive sleep apnea, narcolepsy, motion-induced sleep, periodic limb movement on sleep, and restless leg syndrome) or acute and chronic medical conditions on daytime sleepiness or fatigue and related cognitive performance (Smolensky et al. 2011). Prevalent medical conditions affecting sleep include allergic rhinitis, asthma, lung disease and arthritis (39 more are listed by Smolensky et al. (2011)), but we know little about the relative operational risks of each condition. Work itself may be cause of some disorders e.g. insufficient sleep syndrome and shift work disorder (Lerman et al. 2012). Shift work disorder is a clinical condition involving misalignment of circadian rhythm associated with health problems, with the following diagnostic criteria (Wright Jr et al. 2013):

- Insomnia or excessive sleepiness temporally associated with a recurring work schedule that overlaps with normal sleep time
- Symptoms present for at least 1 month
- Sleep log / actigraphy monitoring for at least 7 days shows disturbed sleep and circadian and sleep time misalignment
- Sleep disturbance is not due to another current sleep disorder, medical disorder, mental disorder, substance or medication use.

Shiftwork disorder is present in 10 and 23% rotating and night shift workers, and can thus be expected in a substantial share of transport operators working shifts. Cessation of shift work is curative, but is often not an option. In such cases management practices are recommended, in which combined measures address alertness, such as naps and stimulants before shift, sleep hygiene and adaptation of the circadian clock to the imposed work schedule (Wright Jr et al. 2013).

In terms of prevalence, sleep apnea is a particular problem, and has been linked to excessive daytime sleepiness and increased risk of car crashes (Belenky & Åkerstedt 2011). It is known to have a relative high prevalence in professional drivers, and surveys showing elevated body-mass index scores for all types of transport operator suggest that that it is a problem for other operators too (Phillips et al. 2015, p.35).

Any of the above disorders can severely impair recovery from work, and there is therefore a need for screening and treatment both of existing and potential employees (Hakkanen & Summala 2000). In particular there is a need to detect sleep disorders, including shiftwork disorders, and treat and evaluate treatment outcomes (Belenky et al. 2011, Wright Jr et al. 2013). The way in which disorders are managed will depend on the organisations and country-specific arrangements for occupational medicine. Employees can be screened using questionnaire items designed to capture chronic fatigue or sleep problems or disorders (e.g. Epworth Sleepiness Scale; Berlin sleep questionnaire). Company medical services should regularly screen physical or mental health status for factors that may increase fatigue risks. Medical screening is carried out by trained personnel – a company doctor, clinician or a visiting doctor – to identify and treat relevant operators. A physical exam should at the very least identify high BMI associated with apnea, and a mental exam for primary disorders such as depression or cancer that can cause secondary problems with sleep will also be important. Such exams may be usefully supplemented by data from sleep diaries or actigraphy if it is ethical to do so. Confirmation of a sleep disorder may require polysomnography at home or in lab (Lerman et al. 2012).

Treatment will vary depending on the sleep disorder or illness. Sleep apnea treatment involves positional sleeping, an oral appliance, or surgery and the processes are well documented (Berka et al. 2005). The employee may need to stay in a sleep lab for one or two nights to confirm that the treatment is working. Training in sleep hygiene can also help recovery. One problem with the treatment of sleep apnea is operator adherence to the treatment, although it is possible to monitor and record adherence rates. Monitoring and compliance needs to be followed up by the treatment manager, and this may be intense for first month, involving calls, surveys, education and data monitoring. Addressing sleep disorders also raises an ethical dilemma i.e. should drivers continue to drive after being diagnosed with apnea? One study also finds that insurers are reluctant to insure drivers who must declare problems with apnea (Bagdanov 2005, Smiley et al. 2009).

Phillips & Sagberg (2010) conclude that screening and treatment is an important part of many attempts at fatigue risk management in transport companies. They summarise attempts at screening and treatment as part of fatigue management in transport organisations as follows:

- 41 % of attempts at fatigue management include screening and treating for sleep disorders that may lead to increased fatigue during transport operations.
- Treatment often includes education (on sleep hygiene) and clinical components.
- Medical screening can be part of a company check-up, or occur as a follow-up to a one-off site visit (Howard et al. 2009) or survey following training session about sleep disorders (Lockley et al. 2009, Smiley et al. 2009).
- Education about sleep disorders to raise driver and manager awareness is often included as part of an attempt at fatigue risk management, and some programmes are strongly centered on identification and non-punitive treatment of sleep disorders (Lockley et al. 2009, Smiley et al. 2009, Leaman & Krueger 2009, Berka et al. 2005).

The effects of health screening and treatment interventions are being increasingly documented. A project by Worksafe Victoria and the Transport Accident Commission in Australia found that out of 12,000 workers given confidential health screening, almost half were referred to their GP, and 24 % found to have a high risk for sleep apnea. An evaluation of the programme reported a significant decrease in lost time injuries. Evaluation of health screening and treatment in North American truckers found that drivers slept longer and more effectively after the intervention, both according to self-reports and actigraph data (Smiley et al. 2009). Scores on a psychomotor task also improved for severely fatigued drivers. Another company found that a sleep apnea management program gave a 30 % reduction in accidents, and two-fold reduction in turnover. A meta-analytic study of the links between sleep apnea and collisions estimates that 980 lives a year would be saved in the US through sleep apnea treatment (Sassani et al. 2004).

Countermeasure 8. Promotion of operator recovery during non-work time

Many road, rail, sea or air operators must sleep away from home during longer transport operations, and companies should attempt to tackle the extent to which sleeping facilities or depots promote rest by considering habitability studies (Poore & Hartley 1998, McCallum et al. 2003). On ships in particular, the psychosocial environment, including the ability to detach psychologically from work, will need to be considered as important influences on fatigue, in addition to physical aspects of the "off-watch" facilities (Sonnentag & Bayer 2005, Sonnentag & Fritz 2007, Sonnentag & Ilies 2011).

Increased risk of accidents has been reported for shift workers in a range of occupations on the job and during the commute home, and the situation may be worse for transport operators who are already fatigued from operating a vehicle before driving home (Åkersted et al. 2005). Even where operators travel as passengers, they do not have the same opportunities for sleep and rest as those who are at home do. According to Office of Rail Regulation (2012) a minimum of 14 h free time between shifts is needed for those travelling home to ensure 8 h sleep is possible. Rest facilities at stations or termini or hotel rooms should therefore be made available for those with short free periods between shifts. The Office of Rail Regulation (2012) guidelines contain a special Appendix devoted to this issue. The fatigue risks related to driving to and from work should be considered by both employers, who have duty of care and are increasingly being asked to consider work-related road risk (ETSC 2009), and individuals, who are responsible for being fit to drive under road traffic laws.

The need to recover from work during free time implies an important role for the individual in transport operator fatigue management, since they are the only ones that transcend work and non-work boundaries. Managers may hesitate to engage operators in a dialogue about their free time, but research on wellbeing provides legitimate ways in which managers can approach the influence of non-work time on fatigue at work. These include the following;

- Increased psychological detachment from work can improve individual well-being and reduce fatigue (Fritz et al. 2010, Oerlemans et al. 2014)
- The concept of life-work enrichment implies that wellbeing at work can be improved by enriching free-time activity (Demerouti et al. 2004, Daniel & Sonnentag 2014, Rodríguez-Muñoz et al. 2014)
- Participative schedule redesign may increase awareness about the importance of free-time activity on fatigue at work (Nielsen et al. 2010, Nielsen 2014)
- Safe commuting approaches (ETSC 2010)

- Work-life balance, family/work interference (Hughes & Bozionelos 2007)
- «Total Worker Health» (CDC/NIOSH, USA)

In fact several organisational attempts to manage fatigue are found to involve personal feedback to drivers on their own fatigue with advice about how to reduce fatigue (Phillips & Sagberg 2010). In one report, driver awareness of their own fatigue risk score was used as a basis for subsequent management by the driver of their own fatigue. Drivers were empowered to adjust their own rest hours as part of the intervention, and coached on how to reduce fatigue scores. The intervention appeared promising, with fatigue risk scores decreasing in line with both driver turnover and accident and injury rates (Moore-Ede et al. 2005).

As we have mentioned, actigraphs can be used to give individuals feedback of sleep history, and this has been done in the rail and road sector, but with only anecdotal evidence about whether the effects were positive (Belenky et al. 1998, Jettinghoff et al. 2005. This can be used as the basis of discussion about ways to change habits (Sherry & Philbrick 2004).

Some approaches encourage employees to proactively seek advice on how to manage their fatigue, through helplines (Gertler et al. 2002) or Employee Assistance Programmes (Railcorp 2005).

"Sleep contracts" can also promote employee recovery during free time. A sleep contract includes:

- A framework for reacting to fatigue, negotiated on consultation with employees
- Standards on how much sleep an employee must contain prior to work
- A statement that it is the employee's responsibility to inform management when these standards are breached, or when they experience fatigue.

In exchange, management guarantees that no sanctions will be taken and an effective management system will be put in place to respond to reported problems. Sleep contracts are recommended by the Energy Institute's guidance for fatigue management, which are in turn recommended by the HSE in the UK (Gall 2006). However, few companies employ sleep contracts, and there are some difficulties with operationalising the terms of sleep contracts (e.g. how tired is too tired?) and lack of employee belief that a management system will be triggered by reporting fatigue are reported (Holmes et al. 2006).

Countermeasure 9. Recovery (fitness-for-duty) monitoring

A countermeasure is effective if it prevents fatigued operators operating. Used just before an operating period, tests of fitness for duty assess the degree to which operators have recovered from previous work in their free time. Several portable computer-based tests or mobile apps are now available, generating performance-based indicators of fitness for duty.

Psychomotor vigilance tests (PVTs) are portable palmtop tests that can be carried out quickly (5 minutes) by the operator, either before starting duty or during breaks. PVTs have already proved useful in operational assessments of the effect of different rosters on fatigue in the field (Jay et al. 2005, van Dongen & Mollicone 2014), although further validation under operational conditions is desirable. PVTs were rated highly relative to other fitness-for-duty tests in a review by Dawson et al. (2014) as having strong evidence for independent validation as a test of sleep-related performance deficits. Similar auditory tests are also promising, and may be able to tap into higher mental abilities in addition to vigilance (working memory and decision making) (Tyagi et al. 2009). The latter could have particular relevance for operators like train drivers, whose higher level thinking may be particularly important for safety (Phillips & Sagberg 2014). Other fitness-for-duty tests include bench-top or portable devices are available that monitor pupil characteristics to give instant estimates of driver alertness (e.g. PMI Inc's FIT2000/2500, Gertler et al. 2002, Heitmann et al. 2009, Shahidi et al. 2009). Ahlstrom et al. (2013) have developed a fit-for-duty test based on eye movement measurements and on the sleep/wake predictor, and initial tests show that it was able to predict 82 % of cases of severe sleepiness in a subsequent drive. The authors admitted that shorter tests need to be validated in the field, and claim that future improvements of a fit-for-duty test should also account for individual differences and situational/contextual factors. Fitness-for-duty devices can also be used to calibrate biomathematical software in order to improve prediction of fatigue levels for the individual driver (Balkin et al. 2010). One problem to be addressed is that there is no widely recognised "fail" performance level equated to a fatigue level.

Survey items can be based on measures of subjective fatigue, such as the Karolinska Sleepiness Scale or the Groninger Sleep Quality Scale, or they may be tailor-made fit-for-duty tests (Wilschut et al. 2009). An assessment using items based on established need for recovery scales is also worth considering (Sluiter et al. 2003, Demerouti, Taris et al. 2007, van Veldhoven and Broersen 2003). These tests can also be performed using a portable tablet or phone, perhaps by accessing a website that collects organisational data. Subjective tests are not considered reliable in isolation, and should therefore be used alongside other estimates of fatigue where possible. Surveys of explicit measures of fatigue can be used alongside fitness-for-duty devices to help inform managers and drivers about whether it is safe for the driver to embark on the trip (Wilschut et al. 2009). More field studies are needed for the different fitness-for-duty indicators, as well as guidelines on how they can be accepted and used in practice (Phillips and Sagberg 2010).

Analysing the extent of recovery is not in itself a countermeasure if the organisation does not act to prevent operators who are not sufficiently recovered from operating. Doing so will involve discussions about acceptable levels of fatigue, and the extent to which this can be inferred from performance indicators. It will also require that drivers can be replaced as necessary, or that operations can be delayed. Whether this is possible will depend to a large extent on the framework conditions of the particular transport branch in question.

3.3.3 Level 3. Reports of fatigue and behavioural symptoms

Due to the unpredictable and widely varying demands placed on transport operators, and the large variation among individuals, it will in many cases not be possible to avoid fatigue surfacing to some extent during an operating period (Hartzler 2014). It will therefore be necessary to help operators identify severe fatigue arising as they operate, preferably before it leads to reductions in safety performance. Where this is possible, identification of fatigue symptoms should be considered a countermeasure in its own right, since informed operators will be able to take mitigating action once they become aware of their own developing fatigue. This will require guidance on implementing effective countermeasures against fatigue developing during operating periods.

Countermeasure 10. Identify fatigue symptoms while operating

Subjective identification of symptoms

Fatigue symptoms can be identified by encouraging or prompting standardised self-assessments by operators with open reporting, and/or by objective measurements of developing symptoms. Own risk assessment and control is possible where employees are alert to the physical, mental and emotional signs of fatigue in themselves and others (Lerman et al. 2012). Mental signs include failure to communicate or remember important things, and emotional signs include withdrawing from others or lacking motivation to the task. Training and use of standard measures such as the Samn-Perelli or Karolinska Sleepiness Scales can increase the extent to which self-assessment is possible, but there is still a lot of uncertainty about operator's own ability to recognise developing fatigue, with several studies concluding that operators are poor estimators of their own susceptibility to drowsiness (Verwey & Zaidel 2000). Attempts at self-assessment should thus consider research by Howard et al. (2014), who found that drivers' ability to recognise fatigue effects on own performance was improved by asking about specific symptoms of sleepiness, instead of general sleepiness, using the Tiredness Symptoms Scale (Schultz et al. 1991). Symptoms relating to visual disturbance and impaired driving performance were most accurate at detecting lateral driving position, implying that drivers may be better at identifying symptoms that match the behaviour of interest.

According to the Office of Rail Regulation (2012), all staff should have an awareness of how to recognise fatigue in themselves or others and this would be helped by education on critical signs and symptoms. Once identified employees must feel that they can openly report fatigue in themselves or others in line with just culture (Reason 1998). Conditions in many branches may not be conducive to the open reporting of fatigue e.g. underreporting by individual seafarers not wishing to jeopardise their company under legislative scrutiny (Smith 2006). (We consider the importance of culture more under organisational-level measures.)

Objective identification of symptoms

Objective measurement of fatigue symptoms using technology addresses concerns that operators are poorly able to recognise their own deteriorating fatigue states. For lone operators, without peer observations, these technologies are even more important. Anund et al. (2015), summarising reviews by Wilschut and Caljouw (2009) and others, classify systems for objective measurements available to road transport companies as (i) drowsiness detection systems, (ii) those detecting absence of physical activity, (iii) those developed and being developed by the car industry, largely based on lane position and steering indicator, and (iv) multiple measure approaches (e.g. ASTiD, DDS, SafeTrac). They conclude that no system in isolation can provide reliable systems for on-line fatigue management by drivers (Anund et al. 2015). More developed technologies for measuring indicators of fatigue can be classified more simply, according to whether they measure physiological or performance indicators of fatigue.

Physiological indicators of fatigue measured include eye-closure, blink rates, blink speed, gaze direction, eye saccadic movement, yawning, and head nodding and orientation, pupil dilation, head position, brain-wave activity (Dinges et al. 2006, Lal & Craig 2001, Craig et al. 2011, Hanowski et al. 2011). Other physiological measures proposed to measure fatigue (HRV, skin conductance, breathing) have little validity (Anund et al. 2015).

An example of an instrument measuring eye closure is the PERCLOS system that monitors the eyes by video and calculates the percentage of time per minute that they eyelid covers 80% of the pupil. The system is reviewed by May & Baldwin (2009) as being validated as correlating with safety performance (lane departures, subjective sleepiness, PVT lapses). Compared to EEG algorithms, eye blink software and head nodding technology, it is more highly correlated with PVT performance decrements (Dinges & Mallis 1998). PERCLOS is available for use in systems like DD850 from Attention Technologies, which plugs into cigarette lighter and can stay with the driver and be used in his next vehicle. Volume, brightness, sound and sensitivity controls allow you to adjust the monitor to suit the driver and his/her cab. An audible alarm sounds when the unit detects that the driver is getting drowsy. Visual feedback shows how long the eyes were closed for and how far the driver drove with their eyes closed.

Sigari et al. (2014) describe how data on several facial indicators is fed into one of several different types of algorithm that output predictions of alertness. As alertness decreases, the systems may trigger information or warnings to the driver or, where systems are centralised, to a control centre.

It is becoming increasingly viable to monitor brain waves as indicators of fatigue using polysomnography with technologies such as SmartCap or B-Alert. SmartCap is a cap that operators wear that reportedly monitors individual's ability to resist sleep. It allows each operator to proactively manage their own fatigue by providing alerts in real time, in terms of fatigue level warnings, which the operator must cancel by pressing a button. Data stored on board can be sent for centralised monitoring, giving ease for inclusion as part of an organisation's fatigue risk management system (Dawson et al. 2014). Threshold scores are derived from an establish test related to micro-sleep occurrence. The similar device, B-Alert, appears to have better validation support, but commercial development has been limited[4]. A recent review of research on neurophysiological measurements in pilots and drivers during their operating tasks is given by Borghini et al. (2014). Real-time analysis of mental state is predicted to be available before 2020. Future application of these findings could result in technologies for monitoring crew interactions (air and sea), and interactions between pilots and ground or aerial vehicles.

Instruments are available measuring *performance indicators* of fatigue, such as the psychomotor vigilance task (e.g. PalmPVT), which is sensitive to several safety-critical cognitive aspects of transport operation, including attentional lapses, and has other desirable psychometric properties (Dinges & Powell 1985, Balkin et al. 2011).

[4] This is a headband-like device and emits messages related to EEG signals classified as sleep onset, relaxed wakefulness, and low and high engagement.

Table 3 summarises further drowsiness detection technologies.

Table 3. Summary of drowsiness-detection systems, taken from Wilschut et al. (2009) and Dawson et al. (2014). The aim of most systems is to alert the driver to deteriorating condition by emitting audible/voice and visual alarms. For more details and source information for individual technologies see Dawson et al. (2014).

System type	Example	Description
Based on eye detection	CoPilot, Optalert, Driver Fatigue Monitor, Driver State Monitor, Attention Assist, FaceLAB, CRAM, ETS-PC Eye Tacking System, AntiSleep, Seeing Machines DSS, Eye-Com, Smart Eye.	Mostly based on infra-red tracking or facial recognition algorithms. Some take PERCLOS-type measurements and/or blink rate. Some supplement with lane deviation analyses. Some require operator to wear glasses i.e. invasive.
Based on EEG	Smart Cap, B-Alert	Detect brain activity corresponding to fatigue levels. Have potential for high validity, and under rapid development.
Based on head movement	MINDStim, Proximity Array Sensing System, NapZapper, Stay Awake, Driver Fatigue Alarm, No Nap.	Based on capacitive sensors and detect head movement. Detect audible and visual alarm on nodding off. Considered late warning devices.
Developed in the automobile industry	Nissan Drowsy / Inattentive Driver Warning, Toyota Driver Drowsiness Detection and Warning System, Daimler AG's Attention Assist	Mostly based on eye detection. Attention Assist combines eye detection with lane tracking.

Many car manufacturers were involved in the use of systems being developed, or were developing their own system. Fleet managers might therefore consider detection systems offered by their provider as part of awareness raising.

Reviews by several authors indicate that these technologies offer much promise but often meet challenges in the field. For instance, CoPilot – the best best known system based on percentage eye closure – is not recommended in US due to poor performance in field (Dawson et al. 2014). The effect of using Optalert to give feedback on scores linked to the Johns Drowsiness Scale, to military personnel on duty and while commuting was assessed and found to lead to reduce drowsiness scores over time, although the effect was small (Aidman et al. 2015). Authors still claim that we lack evidence that instruments measuring objective indicators of fatigue can reliably detect meaningful changes in performance, and in this sense, PVT may remain the best indicator of fatigue (Williamson & Friswell 2013, Anund et al. 2015). According to Lerman et al. (2012) we also lack field trials needed to validate these instruments in real operating contexts. They also list the following questions to be answered before these technologies can be deployed:

- When would the test be administered?
- Would participation be mandatory?
- Who would obtain the test results?
- What actions would be taken?

The technologies also face the same challenges as biomathematical models, in that only predicts fatigue levels, and not risk for actual task being conducted. Reviewing the technology involved in systems based on detection of various facial features, Sigari et al. (2014) conclude that:

- Commercial use is not yet common, but the involvement in research and development by large automobile companies makes it likely that these technologies will appear soon.
- More work is needed to produce systems with sufficient accuracy for commercial use.

- One way to increase accuracy is to base predictions on data from the monitoring of several face-based indicators, but this increases computational complexity. There is a trade-off between accuracy and processing speed.
- Other problems are detection of facial features – especially eyes – for drivers wearing glasses or with varying skin colours, although infra-red imaging is promising; methods for tracking eyes or other features while the head rotates and moves in and out of plane; symptom extraction, especially in the dark.

As concluded by Wilschut et al. (2009), it is probably still true to say that no single system exists that is accepted as validated to detect driver fatigue. Of continuous operator monitoring systems assessed by Dawson et al. (2014), the Optalert and B-Alert systems scored highest on criteria for independent validation and development, and concurrent validity (tested against established fatigue measures such as PVT and polysomnography). Technologies that will be most successful in the future will probably be those combining different metrics, such as ASTiD, which combines sleep history, current driving conditions and steering dynamics to assess fatigue risks (Dawson et al. 2014).

Drowsiness detection to allow remote monitoring of driver fatigue are used in the mining and road transport industries (Aidman et al. 2015). Although there are no commercially available fatigue detection systems for rail, many of the systems developed for road operators would presumably apply. Managers should also consider how operators respond to any feedback they are given based on objective feedback. Some technology generates a shrill alarm, ear piece or seat vibration to the driver, and there is a need to evaluate how operators respond in the longer term to false alarms, and whether operators will compensate for perceived reduction in risk by operating more when they are fatigued.

Summing up their review of on-line operator or performance monitoring as level 3 countermeasures, (Dawson et al. 2014) state that "…organisations have adopted and implemented [countermeasures] with little consideration of the consequences of risk mitigation based on a technology that is not yet legally or scientifically defensible". There is also very little validation data in peer-reviewed literature, and too little explanation of basis of fatigue warning thresholds. However, these technologies are very much suited to fatigue risk management based on measures and outcomes, as such they are likely to become increasingly important. More independent field trials are therefore needed, as well as new technologies that are sufficiently sensitive and adaptable to different types of transport operation.

Countermeasure 11. Containing fatigue while operating

According to May & Baldwin (2009) it is important to distinguish between sleep- and task-related forms of driver fatigue when considering which countermeasure should be applied during operating (May & Baldwin 2009). Technology may help in detecting both forms of fatigue, but whereas the task-related fatigue can be relieved by technologies varying work demand levels, sleep-related fatigue is resistant to such strategies. Furthermore, there are two forms of task-related fatigue: active (high demand driving conditions) and passive (underload conditions, monotony) (Desmond & Hancock 2001). Passive task-related fatigue may worsen sleep-related fatigue. For sleep-related fatigue, the operator either needs more sleep or needs to work away from circadian dips. For passive task-related fatigue, task variety or regular breaks during monotonous drive may be helpful. For active task-related fatigue, any secondary tasks may need to be reduced or removed. Countermeasures for sleep-related fatigue (caused by accumulated sleep, debt, prolonged wake time and circadian trough) will be far more effective at levels 1 and 2 than at level 3 of the fatigue risk trajectory. At level 3, warnings may be given and so on, but oncoming sleep often cannot be fought off.

The nature of transport operations in the rail, and especially road sector is such that lone operators must take action to mitigate fatigue symptoms that develop while operating. At sea and in some land-based branches, there are more opportunities for rest from being relieved from duties by colleagues. In the rail sector, emphasis is placed on drivers' obligation to report to their line managers or control centre if they become too tired to operate while on duty, although it is perhaps less certain what lone drivers in the rail sector should do if they experience initial symptoms of fatigue, in order to prevent fatigue developing.

Countermeasures that lone operators can employ while operating that have a documented effect on sleep-related fatigue are mainly stopping and sleeping (napping) and, under certain conditions, caffeine intake (Åkerstedt & Landström 1998, Snel & Lorist 2011). There is evidence that when professional and private drivers become sleepy, they tend to rely on less effective methods such as winding the window down or eating (Pylkkönen et al. 2015), even though they are fairly good at rating different methods in order of their effectiveness (Nordbakke 2004, Nordbakke & Sagberg 2007). Armstrong et al. (2010) suggests that measures aimed at *motivating* drivers to select the correct countermeasure is therefore more important than education about which countermeasures. This is supported by survey research (Watling et al. 2014, Watling 2014). However, for professional operators, personal motivation may not be sufficient if they perceive that they cannot employ effective measures (stop and sleep) for commercial or other operational reasons. This needs to be tackled head on by any effective attempt at fatigue management, preferably by legitimising stopping, or where this is not possible encouraging communication of the problem and putting in place procedures to be followed in the event of sleep-related fatigue. Perceived operational constraints implies that there is a need to account for culture and framework conditions in fatigue management (Phillips et al. 2015).

Napping is the most effective non-pharmacological technique for sustaining sleep-related alertness (Caldwell et al. 2008). Although naps do not substitute for a main sleep, they are preferable to other countermeasures that tackle sleep-related fatigue occurring at work because they address the cause (i.e. insufficient sleep) head-on (Hartzler 2014, Ferguson et al. 2008). Concerns about sleep inertia, means that naps should be timed strategically (Hartzler 2014). Western Australian road transport and several aviation authorities have issued guidelines on how a company can draw up napping policy (IATA/ICAO/IFALPA 2015), and studies implying a large variation in the shares of professional drivers using napping to counter fatigue with culture and age, suggest that there may be scope for more napping (Anund et al. 2015, Pérez-Chada et al. 2005, Anund et al. 2008). Recent evidence from Finnish truck drivers suggests that where they can make use of napping (the most effective countermeasure), they do so within the confines of statutory breaks (Pylkkönen, Sihvola et al. 2015). Even when they are more fatigued, however, they did not tend to take extra naps outside of statutory breaks. There was a tendency to use more caffeine outside of statutory breaks when tired, and there was greater dependence on less effective countermeasures.

Caffeine and energy drinks in addition to regular stops are effective temporary countermeasures to sleep-related fatigue occurring while operating, according to both simulator and field studies (Reyner & Horne 2002, Gershon et al. 2009, Rose & Giray 2013, Ronen et al. 2014). However, there will be variation in the extent to which individuals respond to these measures and there may be negative effects on fatigue in the longer term if they are used frequently.

In addition to driver assistance technologies covered in the next section, countermeasures against task-related fatigue symptoms include increased breaks, varying tasks, resting/napping, caffeine, bright light or exercise (Folkard & Tucker 2003, Hartley et al. 2013). Caldwell (2001) have scored countermeasures to tackle fatigue occurring in the workplace on their effectiveness, feasibility and duration. Beyond breaks and sleeping, pharmacological agents are the only countermeasure listed as highly effective. Transport companies will in most cases wish to avoid use of these agents, so the implication is that the operator should be removed from safety-critical duties whenever possible.

Finally, episodes of severe fatigue while on duty should also be captured by the organisation even if no fatigue-related errors are detected. Reporting systems for fatigue are dealt with by sector-specific guidance, which often give examples of fatigue report forms and the information they should collect e.g. Office of Rail Regulation (2012).

3.3.4 Level 4. Fatigue-related errors

At this level we are concerned with what can be done to reduce the chance that fatigue-related errors lead to incidents and accidents.

Countermeasure 12. Performance assistance

In the road sector, fatigue-related errors will normally begin to manifest themselves as small decrements in driving performance. Simply providing drivers feedback on fatigue-related performance errors e.g. vehicle positioning, has been found to reduce lane tracking variability significantly, although the effect will only be temporary and there will be extra cost to the driver (Dinges et al. 2006). Collision avoidance system warnings are also relevant as measures that can prevent fatigue-related errors resulting in accidents. Sensors detect whether vehicle or obstacles come within a certain distance from the sides, back or in front of the car. Audible and visual warnings may be triggered, and even if alerting the driver does not prevent the collision, the severity of the accident may be reduced (May & Baldwin 2009). The potential advantages of embedded performance systems are reviewed by Dawson et al. (2014):

- Non-intrusive, require no action by operator
- Direct measure of safety performance, the ultimate concern
- Potential for greater acceptance by operators vs physiological measures

Systems monitoring embedded performance measures to track the operating task in terms of lane position, speed, braking, distance to vehicle in front, acceleration or fuel economy (e.g. C2-170, SafeTrack, MobilEye, AutoVue, Delphi, Roadguard and ASTiD) can in some cases be linked such that they trigger other systems giving automated driver assistance (Dorrian et al. 2006, Liu et al. 2009). The challenge is in being able to discern which effects are due to fatigue, and which due to other parameters. As we have touched on, this gives rise to concerns about (i) the number of false alarms that may be generated, and (ii) whether the drivers begin to rely on these systems as safety nets, making it possible for them to drive further while fatigued.

In the rail sector there are already systems in place that assist performance to a large extent (ATC, ETMS), and the challenge from fatigue-related errors may be more linked to higher level cognitive processes such as decision-making (Phillips & Sagberg, 2010). In the maritime sector, the navigation process is highly automated but fatigue-related performance decrements may only manifest themselves in situations in which officers need to intervene. Dead-man's switch systems in rail and Bridge Navigational Watch System and associated alarms at sea are reviewed by (Anund et al. 2015). Both attempt to mitigate the effects of a sleeping operator – which we consider here to be a fatigue-related error – by alerting others that may be able to help before an accident occurs.

Countermeasure 13. Fatigue proofing

Dawson et al. (2012) promote the idea of "fatigue-proofing" strategies to make transport operations more resilient to the effects of operator fatigue in situations where it cannot be avoided. The authors describe a number of informal proofing strategies designed to capture and control error that may already be in use in certain transport branches, but may benefit from standardising and formalising them. Examples are given of pilots at sea asking helmsmen to call back commands to ensure what was said was correct, received and actioned; and of air pilots who openly identify themselves as fatigued to co-pilots when not adequately rested. Fatigue-proofing strategies involve pre-signalling of elevated risk and increased scrutiny of potential error (Dawson et al. 2012). Since many such strategies have evolved naturally in the workplace, they already account for cultural contexts and are accepted by workers. Standardisation and integration to fatigue risk management systems may be an effective way to "proof" fatigue error. This requires research into consistency of strategies in use, their effectiveness in terms of fatigue control, and development of standard criteria for practice.

Formal "fatigue proofing" strategies are also available, even though these are not covered by Dawson et al. (2012) in their review. Most technological safeguards ensuring human errors do not lead to incidents or accidents are relevant here. For example, in bus transport, start inhibition, where buses will not leave a bus stop until the doors are closed, might help prevent fatigue-related accidents (Cafiso et al. 2013). In this regard there may be greater potential for systems which ensure that operators must react to confirm they have perceived key safety-relevant signals, such as in rail or at sea, such that fatigue related errors can be detected and managed as they happen (Wilde & Stinson 1983).

3.3.5 Generic organisational measures

In line with safety management systems thinking, the organisation will need to put in place generic measures to support the implementation of countermeasures against fatigue hazards at each of the five levels of the fatigue risk trajectory. These are dealt with briefly here.

Countermeasure 14. Continuous learning

As part of continuous improvement that is part of fatigue risk management, the organisation should monitor and learn from barrier failures at each level of the fatigue risk trajectory, in order to improve countermeasures that are meant to act as effective barriers to fatigue manifestation at each level of the fatigue risk trajectory. In particular, there is a need to establish systematic data collection procedures for gathering information about the role of fatigue in incidents and accidents e.g. status of the operator, sleep history, life outside work, the schedule worked, time of day, time on task, medical factors and so on. Human fatigue may play a role not only in operator error, but in maintenance or planning errors that may have contributed to the incident.

Programs are available to help estimate whether a person was influenced by fatigue at a certain time of day, depending on sleep history (Gertler et al. 2002). Checklists are also available that might help e.g. whether a person overlooked a task element, displayed automatic behaviour, responded slowly or conversed less than normal prior to an incident. Standard reporting forms for fatigue incidents are available from publications and internet of authorities, in which fatigue is assessed on a standard scale (e.g. Samn Perelli), reasons are given for this and actions taken documented. Forms are also available to standardize data gathering on the role of fatigue in unsafe acts. For example, using forms promoted by IATA/ICAO/IFALPA (2015), employees can respond on several items assessing various performance indicators linked to attention, memory, alertness, reaction time and problem-solving ability, mood, attitude and physiological effects. In another example, BP Oil attempted to categorise and structure the information collected on the involvement of fatigue in company accidents using a method developed by the National Transportation Safety Board (Gander et al. 1998, 2005). A two-page form devoted to describing fatigue factors surrounding incidents and accidents is given to investigators. Analysis of fatigue-related safety critical events from naturalistic driving studies may be part of fleet management system in larger fleets, although this will be quite resource-intensive (Dozza & Gonzalez 2012). Truck drivers are increasingly mounting cameras on their dashboards for legal and insurance purposes. Mounting of a face-monitoring camera in addition may offer the chance for companies to improve incident and accident analyses.

Countermeasure 15. Other generic organisational measures

In designing fatigue countermeasures the following approaches are relevant at all levels of the fatigue risk trajectory.

Needs analysis. Generic tools can be used to perform a needs analysis, in which fatigue causes and outcomes are measured over a set period in order to highlight the requirements of a management intervention. Paper or internet surveys can be used to assess driver habits, sleep debt or fatigue indices, and diaries and logs can be used to monitor driver sleep, driving hours and break times (Gertler et al. 2002, Friswell & Williamson 2005) Driver and manager surveys, interviews and focus groups can be used to map the basis of the change needed, and inform pre-/post-intervention comparisons.

Recruitment and selection tools (psychometric tests, behaviourally-anchored competency interviews) can be used to select those drivers more suited to shiftwork, for example, or drivers with more experience or who are free from sleep-related disorders (Trutschel et al. 2009). Despite several epidemiological investigations, it is not possible to identify individual characteristics that can be used as predictors of tolerance to fatigue (Costa 2010).

Published measures and ways of developing **safety climate and culture**, trust, organisational commitment, wellbeing and job design may also be relevant to organisations considering FMP implementation (Mullarkey et al. 1999). Above all, management-employee trust and perceptions of just culture necessary for open reporting will be essential to the success of fatigue risk management and attempts at continuous learning. According to Fourie et al. (2010) advice given by experts to operators often includes steps to create a just safety culture, and engage management and employees' "hearts and minds" and identify and support a fatigue champion (ALPA 2008). According to Gander et al. (2011), the most valid and reliable technological systems cannot succeed unless they are accepted, usable, and integrated into a process by which the fatigued driver receives support. However, research is needed on the effects of culture on fatigue, i.e. we know little beyond the subjective perceptions of experts. Researchers have recently asked whether safety culture concept applies to transport operators, many of whom are isolated from the social interactions with leaders and colleagues in an organisation that are necessary to develop shared culture. All the signs are that organisational culture is nevertheless important (Lee, Huang et al. 2016, Öz et al. 2014, Zohar et al. 2014, Nævestad & Bjørnskau 2014). Features of a positive safety culture for fatigue risk management systems (FRMS) are outlined in a special appendix by Office of Rail Regulation (2012).

Training and education will be key to the success of an FRMS. At a more general level it should be used to inform managers, schedulers, employees, employee representatives and unions, and transport chain stakeholders of the need for and nature of the company-specific FRMS. FRMS can inform about containment of fatigue at the individual level. For managers, training on manning and scheduling may be needed. Training is also appropriate for other generic countermeasures listed here.

Key points in many training modules will be as follows (Phillips and Sagberg 2010):

- Responsibility for fatigue management must be shared by managers and employees
- For employees recovery from work for employees and families, may involve using sleep opportunity effectively, using assessment tools, and seeking help for sleep disorders, reporting when not fit for duty.
- Hazards of working while fatigued
- Symptoms of fatigue
- Impact of chronic fatigue on health, personal relationships, life satisfaction.
- Centrality of good sleep, and how this can be achieved through good sleep hygiene.
- Sleep disorders, their effect and how to recognise them and get help.
- Influence of diet, health and stress on fatigue, how to optimise these elements.

Standard training modules are available to organisations, which can be used to increase knowledge and awareness of fatigue, outline coping strategies or explain how diet and health is connected to fatigue (Phillips and Sagberg 2010). These should be adapted after a needs analysis for the particular organisation. Phillips and Sagberg (2010) conclude that the effects of training packages on actual behaviour, performance or operational measures are not clear and directed group discussions may be a more inexpensive alternative. According to Williamson and Friswell (2013), education about fatigue risk management is poorly evaluated. They and others claim that it should never be the sole approach to fatigue risk management as at best it will only have the effect of increasing the likelihood that other countermeasures are implemented by heightening workplace awareness of the risks of fatigue.

Demonstration of business benefits. Research demonstrating definite benefits for the business intending to implement fatigue risk management may be the best stimulant for management commitment. A recent study suggests that seafarers, maritime authorities and insurers consider the costs of fatigue countermeasures at sea to surpass the benefits (Akhtar & Utne 2013). However, evidence can be found that fatigue management reaps benefits:

- One transport company implemented sleep apnea programs and found a 30 % reduction in accidents and two-fold reduction in turnover (Berger et al. 2006).
- Ricci et al. (2007) demonstrate worse productivity and performance and safety outcomes for elements of a non-transport workforce sleeping poorly.
- Fatigue also has health behaviour (e.g. increased alcohol use or smoking) and primary and seconday health status effects and related costs (Lie et al. 2014).

However, there is a dearth of objectively evaluated case studies of the effect of risk management on safety and health, although we expect more and more examples to be made available. A recent assessment of an SMS implemented for vehicle safety by Roche Australia found that the program was effectively managed and led to a range of process and performance outcomes, with high driver compliance in risk assessment processes and reductions in insurance claims and collision costs (Murray, et al. 2012). A key part of the ongoing success of the program was demonstrating to managers that risk assessment outcomes for individual drivers was linked to collision likelihood.

4 Summary and discussion

This report has reviewed countermeasures available to organisations to reduce the likelihood of undesirable safety- or health-related incidents caused by fatigue in human transport operators. We have divided the countermeasures into 15 types, and then organised them along a risk trajectory, to facilitate safety management thinking. This is summarised by Figure 3, which acts as a useful guide for risk analyses and countermeasure selection by transport risk managers.

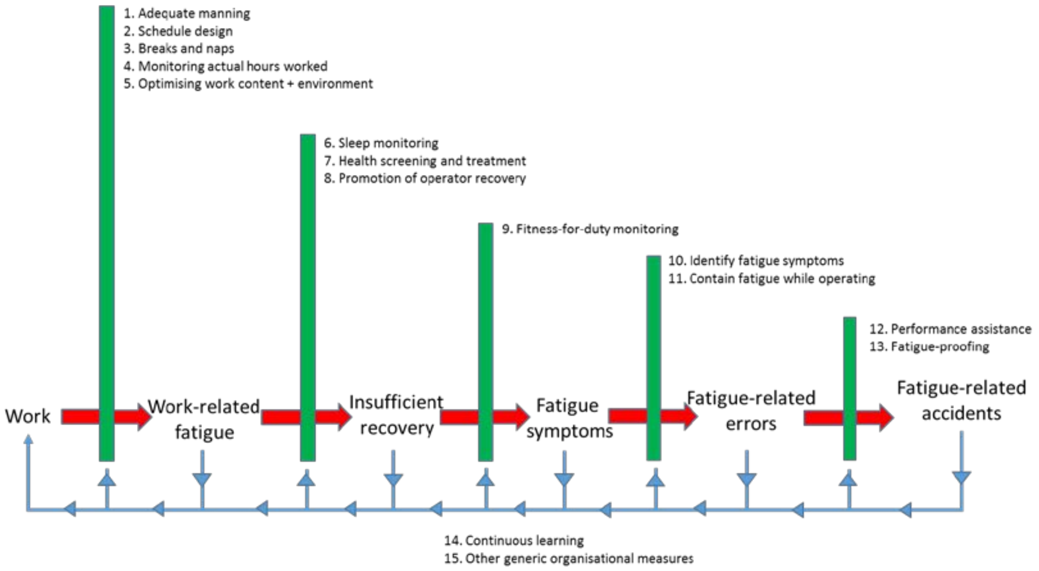

Figure 2. Countermeasures for fatigue in human transport operators arranged along a fatigue risk trajectory. After an initial risk analysis, barriers should be put in place to minimise the chance that work causes fatigue-related accidents. The manifestation of fatigue should be monitored at each step of the trajectory, and used to evolve and evaluate the barriers preceding that step, as indicated by the blue arrows.

In line with safety management thinking, managers should assess the risk that their operators or employees will become fatigued while operating and if necessary put in place barriers to prevent fatigue developing. To begin with, work is examined according to the extent to which it leads to fatigue. If necessary, adjustments are made to reduce the likelihood that inadequate manning, design of schedules, break opportunities, deviations from planned schedules, and the nature of task and work demands result in fatigue. Furthermore, organisations should assess the extent to which employees actually recover from work during the opportunity they are given by their schedule, by monitoring sleep, screening and treating health problems, promoting operator recovery outside of work, and so on.

The manifestation of the fatigue hazard along the trajectory should be assessed by measuring the extent to which work causes fatigue, extent of recovery, fatigue symptoms at work, fatigue-related errors, and fatigue-related incidents and accidents. These aspects should ideally be monitored continually as part of a safety management system, and used to design and evaluate modifications to safety barriers, as indicated by the blue arrows in Figure 3.

Resource-dependent choice of countermeasures

The ultimate choice of countermeasure depends on the organisation's answers to the questions listed in Section 2.9 and the results of the particular risk assessment. The need for safety barriers and the comprehensiveness of the countermeasures they comprise will depend on the chance that the incident will occur, and the seriousness of its consequences. The precise choice of countermeasures will depend on the sorts of undesirable fatigue-related incident the company wishes to avoid, the company's existing resources, competence, technology, infrastructure and culture, the nature of its work or business (e.g. type of goods transported, short or long haul), the framework conditions and regulatory contexts. In particular, a lot will depend on existing procedures for safety management. Specific examples of each countermeasure group are listed in Table 4, to give an idea of different approaches that might be taken by organisations with different resources.

Table 4. Specific examples of each countermeasure group, one for a simple approach to fatigue risk management by a company with limited resources, and one for a comprehensive approach where more resources are available.

Countermeasure group		Example of specific countermeasure	
		Simple	Comprehensive (e.g. FRMS)
1	Adequate manning	Increase number of operators	
2	Schedule design	Use of Åkerstedt (2010) formula or simple guidelines (e.g. Boivin, 2000)	Schedule optimisation based on biomathematical modelling software with input data on actual sleep times
3	Breaks and naps	Plan rest stops in advance	Evaluation of strategic napping intervention
4	Actual hours worked	Compare self-reports / logs of actual working hours with planned schedules	Analyse change in fatigue risk index for actual schedules worked versus those planned
5	Optimise work content	Simple survey to identify and reduce secondary tasks causing fatigue	Human factors / task analysis and optimisation by independent consultant
6	Monitor actual sleep	Wearables giving feedback and tips on sleep improvement via mobile app	Centralised collection of actigraph data to feed into schedule design
7	Health screening and treatment	Develop fatigue checklist in collaboration with doctor to be used at annual check-up	Monthly screening by occupational health service with follow up of disorders influencing fatigue
8	Promote operator recovery	Provide taxi to/from ship/depots after long operating periods	Sleeping facilities at depots, sleep contracts, family training
9	Monitor fitness-for-duty	Mobile app-PVT	PVT results fed into FRMS
10	Monitor fatigue symptoms while operating	Self-assessment with Tiredness Symptoms Scale	Embedded performance monitoring, facial/eye technology
11	Contain fatigue while operating	Promote stopping and sleeping	Promote stopping and sleeping
12	Performance assistance technology	-	Requires further validation?
13	Fatigue-proofing	Increase customer awareness and involvement	Technological safeguards
14	Continuous learning	Regular review and optimisation of countermeasures	Safety assurance, data-driven evaluation of each risk level at regular meetings
15	Other organisational measures	Recruitment	Safety culture development Needs analysis

The table illustrates that fatigue risk management need not be complicated, and only some of the 14 measures will be necessary. Fatigue risk management should therefore be possible even for small transport companies with only a handful of operators.

Business effects

One of the aims of this report was to look at the effectiveness of different groups of countermeasure. In some cases there is good evidence that interventions lead to reductions in fatigue and improvements in safety, e.g. schedule design interventions, job design interventions, health screening and treatment, and fatigue containment while operating (stopping and sleeping or caffeine intake). However, we were unable to systematically compare the effect of different types of countermeasure, in order to prioritise them. This was due to lack of standard measures of effects, a lack of attempts at evaluations, and the complex interacting nature of the countermeasures. For instance, while there is good reason to believe that manning interventions are effective ways to tackle fatigue (fatigue levels are linked to manning levels), we are not aware of any before-after evaluation of the effect of interventions to increase manning on fatigue. Similarly, despite scientific support that they would reduce fatigue, research is needed to evaluate interventions involving the following countermeasures, in terms of their effects on fatigue-related health and safety:

- monitoring of actual hours worked versus planned schedules
- actual recovery from work
- fitness-for-duty monitoring
- promotion of recovery outside work
- performance assistance while operating
- formalisation of fatigue-proofing.

There is also a need to evaluate the implementation of whole systems for fatigue risk management. Indeed, the crux in promoting fatigue risk management by organisations is establishing a believable business case for managing fatigue. Independent of type and size, all companies must be convinced of the economic or other advantages of accounting for fatigue, or at least that accounting for fatigue does not place it at a disadvantage in its sector. On the whole we need to know more about what drives an organisation to want to implement fatigue risk management. Industry surveys would help clarify the picture, and identify organisational "drivers" for implementation of fatigue risk management.

New technology for centralised data collection

Smart cards that record start and end times in relation to planned schedules, and ensure that fatigue training or health check-ups are up to date, and include other data to monitor the effectiveness of fatigue risk countermeasures along the risk trajectory are exciting developments. Such technology could also be used to monitor trends in shift swapping and overtime and sickness absence for any warning signs that the workforce or individuals are being subjected to increasing fatigue. As pointed out by Dawson et al. (2014), for purposes of anonymity such data can probably only be collected at group level. Innovative research is needed in this area to demonstrate the possibilities to transport risk managers.

Which role should other transport actors play?

In a previous report we have pointed to the need to involve other transport chain actors in fatigue management (Phillips et al. 2015). With this in mind, it is worth considering how shipping agents, customers etc. could help with the approach to fatigue risk management described here. Some ways in which they could help are as follows:

- By setting demands on transport company to demonstrate / show certification in fatigue risk management process.
- By setting demands on minimal manning.
- By setting "safe" delivery deadlines that account for optimal schedule design.
- By considering how the passengers or goods carried influence operator fatigue.

In Norway there has been much success with a project called *Trygg Trailer* (Safe Trailer), in which customers are trained such that they can check the technical integrity of trucks before they start to deliver the customer's goods. Customers are motivated to be involved because it is in their interests that their goods are delivered safely and punctually. One can imagine that in a similar way, customers or depot managers might be motivated to check for fitness-for-duty or symptoms of fatigue in drivers before they embark on their deliveries. This would not be easy, however, since it would involve the development of a culture of trust and openness between buyers, drivers and their employers.

Can organizational fatigue risk management improve road safety and health in the general population?

This is a question we have posed before (Phillips & Sagberg 2010). It is reasonable to expect that attempts at fatigue management directed at a wide range of occupations – not just professional drivers – would result in reduced fatigue and thus increased safety at work and while driving for work, as well as improved health and wellbeing. The countermeasures we have described here could be introduced through any occupational HSE system. In addition, there are several reasons to believe that organisational level interventions to control fatigue in the general driving population would be more effective than more traditional road safety campaign approaches. An organisational approach allows for direct personal contact with the target driver, and this is thought to increase the effectiveness of safety messages (Phillips et al. 2010). It also offers access to group pressure mechanisms, enables the effects of positive safety culture to be leveraged; and offers the possibility of incentive systems. Despite this, very few company-level attempts at fatigue management are directed at both occupational and non-occupational drivers. More research is therefore needed to assess such approaches.

The report's limitations

Firstly, rapid developments in technology expand the possibilities for fatigue mitigation at a rapid rate, and descriptions of particular countermeasures will already be out of date by the time the report is published. This is only a minor issue since the main aim of the report is to describe how risk managers should approach the selection of countermeasures and to give an idea about the sorts of countermeasures that can be selected.

Secondly, while an attempt was made to carry out the review completely systematically, we found that the report was enriched by considering reports that we knew of that did not come up in the literature review. Since a large number of reports had to be reviewed, we could not review each abstract in detail, and so inevitably some articles will have been missed. Likewise, there is a large amount of "grey literature" in this area that will not show up in literature searches. Practitioners in this area have valuable knowledge of this literature as well as hands-on experience. They are encouraged to supplement this review by writing about what they know.

5 Conclusion

There is increasing recognition of work-related fatigue as a public health problem, exacerbated by increased demand for round-the-clock operations in a globalized society. At the same time there are increasing calls for organizations to mitigate fatigue in employee operators responsible for transporting goods, passengers or themselves during work time, or to and from work. An effective way to do this is by selecting the following types of countermeasures for fatigue that together form safety barriers along a fatigue risk trajectory.

1. Adequate manning.
2. Schedule design.
3. Breaks and naps.
4. Monitoring of actual hours worked.
5. Optimisation of work content.
6. Monitoring of actual sleep.
7. Health screening and treatment.
8. Promotion of recovery.
9. Monitoring of fitness-for-duty.
10. Monitor fatigue symptoms while operating.
11. Containment of fatigue while operating.
12. Assisting performance with technology.
13. Fatigue-proofing.

Normal prerequisites for effective safety management are also important, i.e. just culture, continuous learning, training, etc.

The exact choice of countermeasure will depend on the risk assessment, the company's framework conditions, resources and characteristics, and effectiveness, although the latter may be unknown before the intervention is evaluated.

A near-explosion of new technologies such as apps and wearables gives new ways for measuring fatigue and recovery, making "defences-in-depth" approaches available to more transport companies, independent of their resources. The framework we present also suggests ways in which transport chain actors other than employing organizations have an important role to play in fatigue mitigation.

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