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Transportation Research Part F 000 (2001) 000-000

TRANSPORTATION  
RESEARCH  
PART F[www.elsevier.com/locate/trf](http://www.elsevier.com/locate/trf)

## Fatigue and alertness in the United states railroad industry part II: Fatigue research in the Office of Research and Development at the Federal Railroad Administration

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Received 1 September 2000; received in revised form 4 December 2000; accepted 18 December 2000

### Abstract

11 The Federal Hours of Service Act of 1907, which regulates the US railroad industry, imposes both  
12 maximum work hours and minimum rest periods. However, this act does not limit employees' weekly or  
13 monthly work hours, restrict the irregularity or unpredictability of on-call work schedules, or restrict  
14 mandatory commuting distances without compensatory time off. Extensive night work, irregular work  
15 schedules, extended work periods with few or no days off, and the policies, procedures, and agreements that  
16 encompass these work scheduling practices, all evolved within the limited provisions of this act. It is not  
17 clear, though, that broad changes in the hours of service laws are the answer to these problems. Conse-  
18 quently, the Office of Research and Development at the Federal Railroad Administration, with its Fatigue  
19 Research Program, has embarked upon a non-prescriptive approach to better manage fatigue in the rail-  
20 road industry. This program includes the development and implementation of improved fatigue data  
21 collection methodologies, better measurement and evaluation tools, and more effective fatigue counter-  
22 measure strategies. The North American Rail Alertness Partnership (NARAP) has become an important  
23 means for understanding the fatigue-related problems in various operational settings, and for identifying  
24 specific programmatic areas that will better meet the needs of the industry. The program goals of improving  
25 the feasibility, utility and cost effectiveness of fatigue management are to be realized with the cooperative  
26 efforts of the government, unions, and the railroad industry, particularly though NARAP, and by broadly  
27 disseminating important technical findings through journal publications and conference proceed-  
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29 *Keywords:* Railroad; Fatigue; Alertness; Shift work; Work schedules

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## 30 1. Background

31 The Conference theme of non-prescriptive approaches to managing fatigue in transportation  
32 would normally present a unique challenge to government researchers, who work within a reg-  
33 ulatory framework that requires scientific and technical support for its rulemaking activities.  
34 Fortunately, a new approach for improving safety in the US railroad industry was initiated in the  
35 1990's by the Federal Railroad Administration (FRA) under the administration of Joline Moli-  
36 toris. As stated in a recent report by the General Accounting Office (1997), "Rather than citing  
37 violations and civil penalties as the primary means to obtain compliance with railroad safety  
38 regulations, FRA has emphasized *cooperative partnerships* with other federal agencies, railroad  
39 management, labor unions, and the states."

40 One of the outcomes of this new partnering approach to safety is the North American Rail  
41 Alertness Partnership (NARAP). As outlined in its charter, the purpose of North American Rail  
42 Alertness Partnership charter (1998) is "to support industry-wide initiatives through the coordi-  
43 nation, facilitation, and communication of efforts to reduce fatigue and promote safety in rail  
44 operations" and "to promote the safety of the industry's employees by developing effective  
45 countermeasures, based upon analytical and/or scientific data" (North American Rail Alertness  
46 Partnership strategic plan, 1997). NARAP members include key government, labor and man-  
47 agement officials, who meet on a quarterly basis.

48 FRA's Office of Research and Development (OR&D) has embarked upon a Fatigue Research  
49 Program. This program will systematically assess the many underlying factors that result in fa-  
50 tigue and reduced alertness, and develop appropriate tools that will assist the industry in devel-  
51 oping its own effective fatigue management solutions. The program goals of enhanced alertness  
52 and performance are to be realized through FRA's cooperative approach with labor, manage-  
53 ment, and other government agencies, in particular NARAP. The OR&D also expects to ac-  
54 complish its program goals by broadly disseminating important technical findings. Three areas of  
55 research are needed to better understand fatigue problems and to help foster effective fatigue  
56 management programs in the US railroad industry: (1) fatigue data collection, (2) valid and re-  
57 liable fatigue measurement and evaluation tools, and (3) fatigue countermeasure strategies.

## 58 2. Fatigue data collection

59 As in most industries, consistent and reliable data on fatigue (particularly good exposure data)  
60 is often lacking in the railroad industry. For example, a recent study, entitled Switching opera-  
61 tions fatalities analysis (in press), indicated that fatigue could not be investigated as a contributing  
62 factor to fatalities because the relevant data was missing, incomplete, or lacked good exposure  
63 measures for establishing appropriate rate information. Even though this study involved nearly  
64 two years of cooperative effort from management, labor, government and other human factors  
65 researchers, no definitive conclusions on fatigue-related fatalities could be established. Another  
66 preliminary study conducted by Foster-Miller, found FRA's accident/incident database useful for  
67 determining overall trends, but is limited in its usefulness for determining principal factors in-  
68 volved in incidents and injuries. Despite this, fatigue-related incidents are generally considered to  
69 be much more prevalent than the data suggests (Sussman & Coplen, 2000).

### 70 2.1. *Incident data and incident investigation methods*

71 Because there is limited fatigue-related data available for conducting good quality statistical  
72 analyses, the FRA is planning to modify its incident reporting system to include fatigue-related  
73 factors. The FRA is also planning to modify its incident investigation methods and training to  
74 recognize fatigue as a possible contributing factor to incidents. OR&D plans to provide the re-  
75 quired technical support needed for developing standardized fatigue data to be collected during  
76 incident investigations. OR&D also plans to provide the necessary technical support for the de-  
77 velopment, design and utility testing of software tools needed for reliable and consistent collection  
78 of fatigue-related data.

### 79 2.2. *Near-miss data*

80 Efforts are also underway to evaluate the feasibility of developing a near-miss incident reporting  
81 system in the railroad industry. For every actual incident, many more near-miss incidents occur.  
82 With a much larger data set assumptions can be minimized, additional analyses can be conducted,  
83 and results can be interpreted with a greater degree of confidence. Although the FRA already  
84 requires the collection of near-miss data related to the safety conduct of locomotive engineers  
85 (Title 49 Code of Federal Regulations, Part 240 Section 309); fatigue-related analyses of this data  
86 set have not been conducted. Such data could be assessed by using tools such as those mentioned  
87 in the Section 3.3. This type of analysis could potentially indicate if there is any relationship  
88 between fatigue (determined from the pattern of work from the prior seven days) and near-miss  
89 occurrence. OR&D is planning to evaluate the validity of available software programs that an-  
90alyze fatigue as a possible contributing factor to both near-miss data and incident data.

### 91 2.3. *Work schedule data*

92 OR&D has begun a project to develop a database of railroad work schedules so that ergonomic  
93 assessments and comparisons of different work schedules on fatigue and performance can be  
94 conducted. This project will also provide important categorical information that can be included  
95 in any modifications to the incident reporting system.

### 96 2.4. *Other fatigue data*

97 Event recorders are the “black boxes” on locomotives that record most performance activity,  
98 including speed, throttle position, dynamic braking, air braking, etc. It is possible that these  
99 devices may be a useful source of data for evaluating the effects of different pilot projects on  
100 fatigue. To date, however, no known studies have utilized this method of data collection for  
101 evaluating the effectiveness of the field interventions currently being implemented by the industry.  
102 OR&D will review the capability and practicality of this methodology for collecting fatigue-re-  
103lated data and evaluating the effectiveness of field intervention strategies.

104 OR&D collects other fatigue data using a variety of research methods to build a broad base of  
105 knowledge on fatigue and its relationship to operational performance. Some of these method-  
106ologies include structured interviews, surveys, focus groups, work/rest activity diaries, wrist ac-

107 tigraphs, meta-analysis, naturalistic observations, Cognitive Task Analyses (CTA), and literature  
108 reviews.

109 OR&D has compiled a comprehensive bibliography of scientific research on fatigue in railroad  
110 operations which is available on the FRA website. The website can be found at [http://](http://www.volpe.dot.gov/frarnd/rndpubs.htm)  
111 [www.volpe.dot.gov/frarnd/rndpubs.htm](http://www.volpe.dot.gov/frarnd/rndpubs.htm). This bibliography references only peer-reviewed articles  
112 in academic journals or academic books with railroad operating employees as subjects. A liter-  
113 ature review is being conducted on the impact of extensive travel and commuting times on fatigue  
114 and performance in non-operating personnel. A bibliography of this literature will also be  
115 available on the above website.

### 116 3. Fatigue measurement and evaluation

117 A systems approach for measuring and evaluating fatigue and its effects on *operational per-*  
118 *formance* is also needed. Research is being conducted in four major areas to develop valid and  
119 reliable tools that can aid in the measurement of fatigue and its effects on operational perfor-  
120 mance: (1) cognitive workload, taskload and performance modeling, (2) job analysis and staffing  
121 analysis, (3) work schedule evaluation, and (4) locomotive simulator experiments.

#### 122 3.1. Cognitive workload, taskload and performance modeling

123 Good predictive models of cognitive workload/taskload are needed to aid in the measurement  
124 of fatigue and to evaluate its effects on alertness and performance. Predictive models will also help  
125 evaluate the effects of changes in system states and enable “what if” type questions to be asked, so  
126 that fatigue and other performance-related problems can be anticipated before they arise. Using  
127 these models, basic principles can be developed for systematically evaluating the effects of  
128 changing technology on operator performance and fatigue. These models and procedures for  
129 using them would then be made available to the industry.

130 It is important to use formalized methods, such as cognitive task analyses, to help develop good  
131 cognitive workload/taskload models and other decision-making and performance models, which  
132 can then be further tested and validated. CTA evolved as a collection of methodologies to enhance  
133 human performance by better understanding the cognitive decision-making processes of opera-  
134 tions in complex environments, and thereby support the development of computer-based infor-  
135 mation processing tools. A wide variety of CTA techniques are often employed, including specific  
136 knowledge elicitation techniques, function-based task analyses, cognitive work analyses, concept  
137 mapping, and conceptual graph analyses. One of the most valuable aspects of conducting a CTA  
138 is the systematic documentation it provides on the inherent nature of complex cognitive tasks in  
139 operational settings. Therefore, CTAs are an important mechanism for developing measurement  
140 and evaluation tools for fatigue and its effects on operational performance.

141 OR&D completed a preliminary CTA on railroad dispatchers to determine how experienced  
142 dispatchers manage trains and control track use (Roth, Malsch, Multer, & Coplen, 1999). The  
143 objective was to gain insight into the cognitive demands placed on railroad dispatchers and the  
144 decision strategies they have developed in response to those demands. Results of the CTA will be  
145 used to develop cognitive workload and performance models of dispatchers. New technology,

146 such as Positive Train Control and other computer-based decision aid systems, can then be  
147 evaluated in the dispatching environment for their impact on mediating dispatcher fatigue. CTAs  
148 are being conducted for locomotive engineers, maintenance-of-way personnel and other non-  
149 operating employees.

150 On-going studies are being conducted to develop better measures of railroad dispatcher  
151 workload, stress, and fatigue, which can also be used in performance and alertness models. The  
152 purpose of this project is two-fold: (1) to identify specific job task and work environment factors  
153 that contribute to the three variables of workload, stress, and fatigue among railroad dispatchers,  
154 and (2) to develop and validate appropriate methodologies for measuring each of these three  
155 variables in the dispatching environment. Issues being explored include differences among shifts,  
156 traffic volume effects and time of day effects on the level of dispatcher workload, stress, and fa-  
157 tigue.

158 In addition, a methodology is currently being devised for quantifying dispatcher taskload and  
159 objectively evaluating its effects on stress and fatigue. Once validation studies are complete, a PC-  
160 based system will be designed to assist in the uniform collection and analysis of taskload data.  
161 Such a PC-based system will benefit the industry by providing a ready-to-use electronic mecha-  
162 nism for tracking, monitoring, and evaluating dispatcher taskload. This project has been intro-  
163 duced to the industry at a kick-off meeting with labor and management representatives.

### 164 3.2. *Job analysis and staffing analysis*

165 Job analysis research is being conducted to identify work practices and work environment  
166 conditions that contribute to employee fatigue, injuries and incidents so that remedial actions can  
167 be suggested. A preliminary study conducted by Foster–Miller, established appropriate measures  
168 for evaluating incidents and injuries for employees on different work schedules and working  
169 conditions in yard and terminal operations. Fatigue-related findings suggest that certain yard job  
170 and work schedule categories experience significantly higher injury rates than the industry average  
171 for all railroad and all yard workers.

172 An integral component to work schedule evaluation and design is staffing analysis. Various  
173 staffing analysis software programs are being evaluated for their possible application to work  
174 schedule evaluation and design in the US railroad industry. The goal is to develop a standard  
175 methodology for performing an objective staffing analysis in critical operations (locomotive en-  
176 gineers, dispatchers, etc). This staffing analysis methodology will objectively determine minimum  
177 staffing levels needed as based on existing criteria. A kick-off meeting was recently held with labor  
178 and management to begin this process with dispatchers.

### 179 3.3. *Work schedule evaluation*

180 OR&D continues to analyze fatigue and alertness data collected with work/rest activity diaries  
181 of on-call locomotive engineers (Pollard, 1996). Pilcher and Coplen (2000) evaluated how often  
182 and under what conditions locomotive engineers engage in work/rest cycles less than 24 h, and  
183 what the effects of those work/rest cycles had on sleep quantity, sleep quality, and self-rated  
184 alertness. Further studies are being considered to evaluate the effect of these irregular work/rest  
185 cycles on fatigue and performance, including a review of relevant literature.

186 Various alertness models and fatigue modeling software are also being evaluated for their  
187 application to the US railroad industry. Similar to the fatigue modeling software developed in  
188 Australia for predicting work-related fatigue associated with specific rosters in the Australian  
189 railways (Dawson, Roach, & Baker, 1997; Fletcher & Dawson, 1998), OR&D is developing a  
190 conceptual model for a software tool to evaluate work schedule data in the US railroad industry.  
191 The goals are to develop an easy-to-use tool that will help railroad managers and workers in the  
192 US railroad industry evaluate their own work schedules for their impact on alertness, and to aid in  
193 the design of more ergonomic work schedules. This PC software tool would be able to read work  
194 and sleep data from a variety of possible sources. It produce predictions about alertness levels  
195 over the following 24 h, as well as providing a method for easily producing raster-plot repre-  
196 sentations and deconstructing work schedule data. A research protocol will be designed to further  
197 develop and validate this tool using criteria-based on one or more of available alertness and  
198 human-performance models.

#### 199 *3.4. Locomotive simulator experiments*

200 Simulator experiments allow researchers to explore important safety issues that may be im-  
201 possible in field settings. Simulator research also provides a much higher degree of experimental  
202 control. Thus, they are an important component of OR&D's Fatigue Research Program.

203 In a recent simulator study, Thomas, Raslear, and Kuehn (1997) found measurable decrements  
204 in train handling performance in work/rest cycles of less than 24 h. In addition, they also found  
205 that these performance decrements were worse when the work/rest cycle was about 20 h in length  
206 as opposed to 22 h in length.

207 Napping is a potential technique for alleviating the impact of sleep deficits resulting from work/  
208 rest cycles of less than 24 h. The FRA, with input from a number of international researchers, has  
209 designed a study to evaluate the effects of different nap durations on operation performance in an  
210 advanced high fidelity locomotive simulator.

211 Future simulator research is being planned to study the effects of one-person locomotive op-  
212 erations on fatigue and workload, and to evaluate the ability of cognitive displays, digital com-  
213 munications, and other technology applications to mediate fatigue-related performance problems  
214 in the locomotive cab.

215 Aspects of the physical environment impact operator fatigue and alertness. OR&D is in the  
216 process of conducting a meta-analysis to investigate the relationship between temperature in the  
217 locomotive cab and operator performance. If it is concluded that such a relationship exists, fol-  
218 low-on simulator research will be considered for investigating the impact of this and other aspects  
219 of the physical working environment on crew fatigue and performance.

#### 220 **4. Fatigue countermeasure strategies**

221 NARAP identified eight key components for an effective fatigue countermeasure program in its  
222 North American Rail Alertness Partnership strategic plan (1997), including: (1) education and  
223 training, (2) employee scheduling practices, (3) emergency response requirements, (4) alertness  
224 strategies, (5) evaluation of policies and procedures, (6) adequate rest environments, (7) work

225 environment, and (8) implementation strategies. OR&D's Fatigue Research Program provides  
226 *technical support* for many of NARAP's on-going strategies and activities. OR&D regularly  
227 sponsors speakers at NARAP meetings to help educate its members about fatigue-related research  
228 methodologies and current findings. OR&D is also actively involved in the NARAP Non-Op-  
229 erations Subcommittee, and will provide the technical support necessary to help answer the  
230 question, "Is there an increased risk of accidents/injuries associated with travel to and from work  
231 [in non-operating personnel]?"

232 A number of other fatigue countermeasure strategies are also being planned or implemented by  
233 the FRA. OR&D will be involved in evaluating the effectiveness of different fatigue counter-  
234 measure strategies and technologies employed by the industry.

235 Based on the results of its CTA studies and the development of appropriate models, OR&D  
236 may evaluate, and possibly test: Positive Train Control, digital communication systems, advanced  
237 information displays, and other cognitive-based information systems for their ability to mediate  
238 the fatigue and alertness problems of locomotive engineers and dispatchers. OR&D is also in the  
239 process of evaluating various alertness monitoring devices for their ability to predict fatigue  
240 problems, and their utility in allowing railroad operating personnel to take preventative measures  
241 to mitigate fatigue.

242 Finally, OR&D is participating in a human factors program initiative by the US Department of  
243 Transportation (DOT) to develop and implement tools, methods, and technologies to detect,  
244 measure, monitor, and mitigate operator fatigue in various transportation modes. The DOT re-  
245 leased a Broad Agency Announcement soliciting proposals from individuals, businesses, academic  
246 institutions and other research centers. This solicitation on Operator Fatigue Management An-  
247 alytic Systems and Technologies to Forecast and Manage Fatigue and Ensure Alertness for  
248 Commercial Transportation Operators was published in Commerce Business Daily on June 16,  
249 2000 (Solicitation DTRS56-00-BAA-0007).

## 250 5. Conclusions

251 The Fatigue Research Program in FRA's Office of Research and Development encompasses a  
252 broad variety of data collection methodologies, measurement tools, and countermeasure strate-  
253 gies. Improving our methodologies and practices for collecting fatigue-related data will help us  
254 better understand the relationship between fatigue and specific work-related factors, such as work  
255 schedules, work environment, job task, or commuting. Improving our tools and methods for  
256 measuring and evaluating the effects of fatigue on operational performance will help the gov-  
257 ernment and industry better estimate the true costs of fatigue. Locomotive simulator experiments,  
258 for example, that track and monitor fuel consumption, emergency brakings, braking frequency,  
259 and other operational performance measures, play a critical role in developing and implementing  
260 effective fatigue countermeasure strategies. These studies will not only help identify some of the  
261 cost factors associated with fatiguing work schedules or work environment, but will also help  
262 estimate the cost savings associated with implementing specific fatigue-related countermeasures,  
263 such as strategic napping.

264 In addition, the ability to quickly profile a specific work group or a particular operation, and  
265 then reasonably assess its susceptibility to fatigue, will help the government and industry prioritize

266 and devote our resources to those areas that need them the most. The ability to reasonably  
 267 forecast decrements in alertness and performance for individuals or work groups will help us  
 268 develop more effective fatigue countermeasure strategies. The overall success of this program  
 269 hinges not only on the systematic development of better measurement tools and evaluation  
 270 methodologies, but also on the cooperation and teamwork of industry, government and research  
 271 professionals alike. NARAP has become an important venue for enlisting these cooperative ef-  
 272 forts. With this comprehensive Fatigue Research Program, and the support of NARAP, FRA's  
 273 Office of Research and Development is committed to play a leading role in developing non-  
 274 prescriptive approaches to managing fatigue in transportation.

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