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Report to the Chairman, Committee on Energy and Commerce, House of Representatives

April 1992

RAILROAD SAFETY

Engineer Work Shift Length and Schedule Variability

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Resources, Community, and
Economic Development Division

B-247654

April 20, 1992

The Honorable John D. Dingell
Chairman, Committee on Energy
and Commerce
House of Representatives

Dear Mr. Chairman:

Despite rail safety improvements over the past 10 years, over 3,000 railroad accidents occurred in 1990 that were reported to the Federal Railroad Administration (FRA). In 1990, human factors caused the largest portion (36 percent) of such accidents, in contrast to the situation in past years, when track defects were the most prevalent cause. This report addresses the railroad Hours of Service Act, as amended, which requires that employees (1) may work no more than 12 continuous hours without a minimum of 10 consecutive hours off duty and (2) be given at least 8 consecutive hours off duty in every 24-hour period.

As agreed with your office, we focused our work on answering three questions:

- Are railroads complying with the above requirements of the Hours of Service Act?
- Can safety be improved by amending the act to reduce the maximum number of hours (e.g., from 12 to 10) that an engineer is allowed to work?
- Do work schedule factors other than the maximum number of hours allowed by the act affect safety?

The accident-related findings in this report, including when an accident happened in an engineer's shift, are based on our analyses of the data base containing all human-factor-caused rail accidents reported to FRA by U.S. railroads in 1989 and 1990. As such, these findings apply to all railroads unless otherwise stated.

The findings related to characteristics of engineers' work schedules are based on our analyses of 1990 work schedules for randomly selected engineers from four Class I railroads.[1] These findings apply only to the four railroads we reviewed: Atchison, Topeka & Santa Fe; Kansas City Southern; Southern Pacific; and Burlington Northern. However, these four

[1]The Interstate Commerce Commission classifies railroads by their operating revenues. In 1990 Class I railroads were those with annual revenues of $94.4 million and above. The 14 Class I railroads accounted for 91 percent of the freight revenue for all U.S. railroads.

represent about 36 percent of the freight ton-miles carried by all U.S. railroads in 1990.[2]

Although the act governs all members of a train crew, we limited our review to engineers because the accident data always identified the engineer on duty when an accident occurred but not necessarily other crew members. This limitation should not affect our findings concerning compliance with the Hours of Service Act because both industry and FRA officials agree that engineers' schedules reflect the same conditions found in schedules of other train crew members.

Results in Brief

- The four railroads we reviewed were substantially complying with the provisions of the Hours of Service Act. We estimate that, 99.4 percent of the time, engineers were given at least 10 hours off duty following a work period of 12 or more hours. We found no instances in which an engineer received less than 8 hours off duty in any 24-hour period. Our estimates also showed that engineers rarely worked more than two consecutive shifts with 9 or fewer hours off duty between shifts.
- Our analyses of accident data and engineers' work schedules showed that reducing the maximum number of hours allowed per shift from 12 to 10 may have little effect on the number of rail accidents that occur. Only 4.5 percent of all human-factor-caused accidents in 1989 and 1990 occurred after 10 hours in an engineer's shift. At the same time, we estimate that in 1990 about 17 percent of the engineers' work periods at the four railroads lasted more than 10 hours.
- Furthermore, reducing the maximum allowable work/off-duty periods from the current 12-hours-on, 10-hours-off cycle to a 10-on, 10-off cycle could increase the variability—the change in work period start times from day to day—of engineers' work cycles. For example, in the most extreme case, an engineer working 12 hours on, 10 hours off would start each shift 2 hours earlier. An engineer working 10 hours on, 10 hours off, however, would start each shift 4 hours earlier and experience twice as much start time variability. This could, in turn, increase fatigue for engineers who regularly work the shorter cycles.

Scientific research indicates that human beings are naturally less alert in early morning hours from 2 a.m. to 6 a.m. Research also indicates that variability in work cycle start times disrupts natural human sleep-wake cycles and can lead to fatigue, which, in turn, can lead to diminished

[2]Findings related to work schedule characteristics are based on estimates that are subject to sampling error, as shown in app. II. However, all estimates made in this report are at the 95-percent confidence level.

performance. In 1990 more human-factor-caused rail accidents occurred from 2 a.m. to 6 a.m. than in other 4-hour segments at the four railroads we reviewed. We also estimate that the accident rate (accidents per 100,000 engineer hours worked) from 2 a.m. to 6 a.m. was higher than at other times.

Because the accident rate was higher in early morning hours, yet engineer work periods were not longer at that time than during other times, we looked for other factors that might account for a higher accident rate. The start time variability of engineers' work cycles was quite pronounced during the 2 a.m. to 6 a.m. time period, averaging 3.5 to 5.0 hours, according to our estimates. It was also pronounced in other time periods, averaging 2.8 to 4.3 hours. We believe that higher levels of start time variability increase the likelihood that engineers will experience fatigue.

While our findings showed that engineers have variable schedules and that research links such schedules to increased fatigue, many different factors can combine to cause human-factor-related accidents. These may include training, experience, traffic conditions, and the type and complexity of a route. Neither our own analyses nor other research could isolate or quantify to what extent fatigue caused by variable schedules contributes to these accidents.

However, since engineer fatigue is a factor that can influence performance negatively, we urge caution if any changes to the Hours of Service Act are considered that could introduce even greater engineer schedule variability and thereby increase the potential risk of fatigue, particularly in early morning hours. We are currently extending our study to more accurately analyze the length and variability of work periods, off-duty periods, and start times; the type of train (yard, through-freight, or other) involved in an accident; and the location of the engineer (i.e., at home or at an away station) during off-duty periods. We will report on this analysis at a later date.

Background

The Congress enacted the Hours of Service Act in 1907 to enhance safety by limiting the number of hours that railroad engineers and other railroad employees can work. Officials of FRA and the Brotherhood of Locomotive Engineers (BLE), the primary U.S. labor union representing railroad engineers, stated in 1991 congressional testimony that train crews can work difficult and fatiguing work schedules while complying with the act's mandated off-duty periods. BLE supports changes to the act, including reducing the maximum allowable work period from 12 to 10 hours, to reduce train crew fatigue, which BLE believes would increase railroad safety. FRA believes that the act should be repealed and its requirements incorporated into regulations that FRA could change as needed.

Four Railroads Are Complying With Work and Off-Duty Period Requirements

The four railroads we reviewed are essentially complying with the Hours of Service Act. As part of our analyses of engineers' work schedules, we tested the railroads' compliance with provisions of the act requiring that engineers who work 12 hours in a work period must have a minimum of 10 hours off duty. At the four railroads, we estimate that 99.4 percent of the work periods greater than or equal to 12 hours were followed by off-duty periods of 10 or more hours.[3] We also tested the railroads' compliance with the act's requirement that engineers have at least 8 hours off duty in every 24-hour period. We found no instances in which an engineer received less than 8 hours off duty in any 24-hour period.

BLE officials have stated that railroads typically require employees covered by the act to "mark off"—or stop working—after 11 hours and 59 minutes. According to BLE, the railroad can then avoid the act's requirement that the employee be given 10 hours off duty. Instead, the railroad would need to give the employee only 8 hours off duty before requiring him or her to return to duty. We found virtually no evidence of this situation happening to engineers at the four railroads we reviewed. We looked for engineers' work periods lasting at least 11 hours and 45 minutes but less than 12 hours, followed by off-duty periods shorter than 10 hours. The number of instances was so small that we could not make an estimate for the four railroads. We did, however, estimate that only 0.6 percent of the engineers' work periods lasted at least 11 but less than 12 hours and were followed by off-duty periods of less than 10 hours.

Also, FRA stated that the act allows engineers to work consecutive 8-hour-on, 8-hour-off cycles for extended periods. We found no evidence of this occurring at the four railroads.

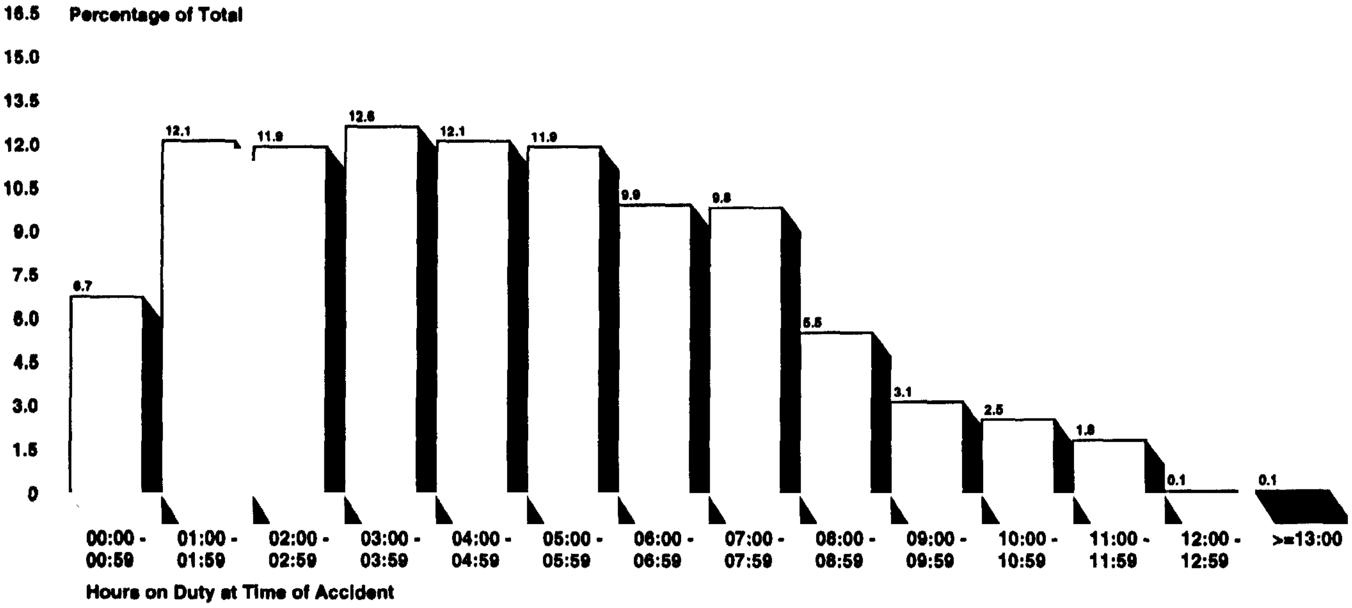
Rail Accidents Occur Early in Engineers' Shifts

In support of their position that the act should be changed to reduce the maximum allowable work hours, BLE officials told us that the longer engineers work, the more tired they become, and the more likely they are to have an accident. However, human-factor-caused accidents do not often

[3]All the sampled work periods greater than or equal to 12 hours were followed by rest periods of 10 or more hours at two of the four railroads. (See app. II.)

occur in the 10th and 11th hours of an engineer's shift. Our analyses showed that, in 1989 and 1990, over 95 percent of the accidents occurred before an engineer worked 10 hours in a particular work period. While accidents occurred in all hours of a work period, the highest frequencies appeared in the second through the sixth hours, and a large drop in accidents occurred after the eighth hour. (See fig. 1.)

Figure 1: Human-Factor-Caused Accidents, 1989-90—Distribution by Hours on Duty at Time of Accident

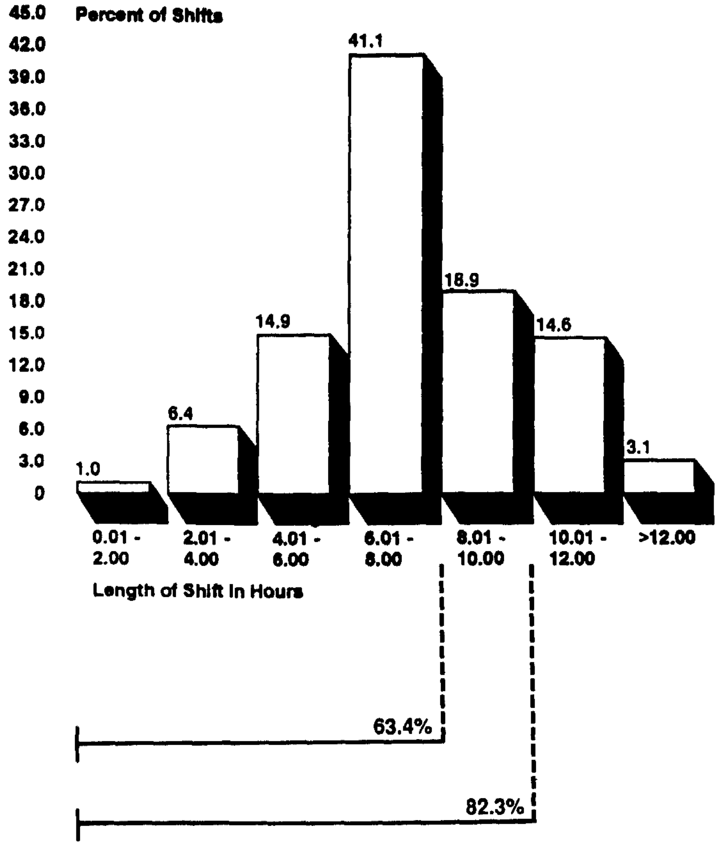


Note: Numbers may not add to 100 percent because of rounding.

Source: GAO analysis of FRA accident data.

The small number of accidents in the 10th and 11th hours of an engineer's work period may be explained by the fact that most engineers work less than 10 hours in each work period. At the four railroads, we estimated that 82.3 percent of the engineers' work periods were less than or equal to 10 hours in length (see fig. 2) and that 63 percent of the work periods were less than or equal to 8 hours.

Figure 2: Length of Shift Estimates



Note: Shift estimates were calculated from 1990 schedule data from four railroads.

Reducing the maximum number of hours allowed per work period under the act may not enhance rail safety. Contrary to the concerns over safety after an engineer was on duty for 10 hours, we found that only 4.5 percent of the accidents occurred after 10 hours had been worked in a given work period. Furthermore, since there is no basis for concluding that working longer hours caused these accidents or that railroads would change their operations, changing the act might not have prevented the 1989 and 1990 accidents.

Work Schedule Variability May Increase Fatigue

Our analyses of engineers' schedules showed that the length and frequency of work cycles in a 10-day period were similar to those experienced by a regular (e.g., 8 a.m. to 5 p.m.) worker. Within a 10-day period, most engineers worked in total about the same number of hours with about the same time off. However, we identified a significant difference in the regularity of work cycles—the change in start times from day to day. Research has shown that work cycle variability can disrupt natural human sleep-wake cycles and can lead to fatigue. This variability, which a regular worker does not experience, may increase engineers' fatigue and could potentially have a greater effect on safety than the number of hours worked per shift. However, many different factors can act in combination to contribute to accident causes, and neither our work nor other research could isolate or quantify to what extent fatigue caused by variable schedules contributes to accidents.

Estimates of Engineers' Work Schedule Characteristics

Our review of work schedules for 1990 from the four railroads showed the following characteristics of an engineer's work cycle:[4]

- In 82.3 percent of the work cycles, engineers worked 10 or fewer hours.
- In 14.6 percent of the cycles, engineers worked more than 10 but less than or equal to 12 hours.
- In 3.1 percent of the cycles, engineers worked more than 12 hours.
- The work period averaged between 7.5 and 8.2 hours.
- The off-duty period averaged between 26.2 and 37.4 hours.

In a 10-day work schedule, the number of hours that engineers worked and had off duty appeared similar to the number of hours worked by people with regular schedules in other professions and trades. A worker on a regularly scheduled, 8 a.m. to 5 p.m., 5-days-per-week work schedule would begin 6 to 8 work cycles in a typical 10-day period, would work a total of 54 to 72 hours, and would be off duty 168 to 186 hours. By comparison, engineers began an average of 6.4 work cycles, worked an average of 47.7 to 53.4 total hours, and had 186.6 to 192.3 hours off duty.

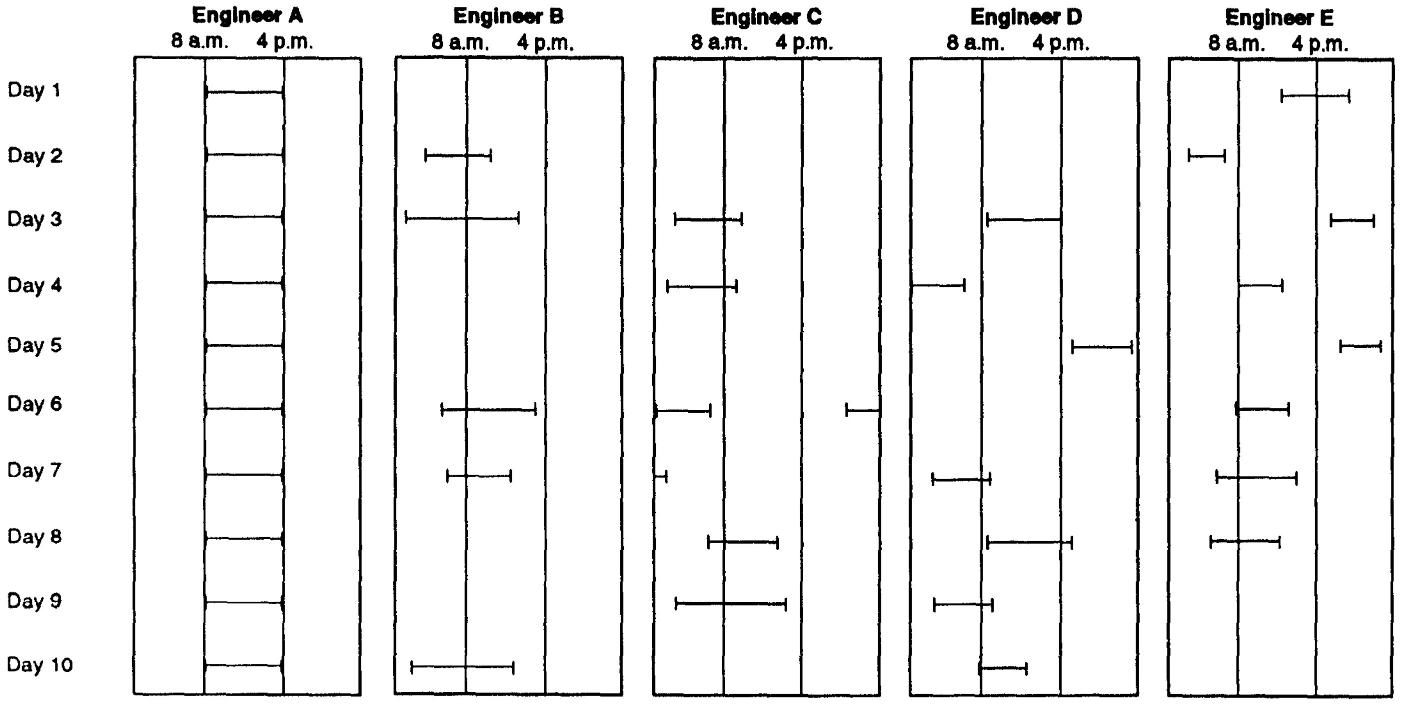
However, an important difference can be seen in the regularity of work cycle start times. The 8 a.m. to 5 p.m. worker begins work at the same time each day and would experience no start time variability. However, the start time for about half of the engineers' cycles varied by at least 2 hours per work period, according to our estimates. Furthermore, an estimated 30 percent of the start times varied by at least 6 hours.

Figure 3 shows actual 10-day work periods for engineers in our sample with start time variabilities of 2, 4, 6, and 8 hours compared with the work

[4]A work cycle is one work period together with one off-duty period. The cycle begins at the time the work period commences and ends when the next consecutive work period begins.

periods for a worker with no start time variability. The figure demonstrates how erratic start times can become as the variability increases. For example, Engineer A—who had no start time variability—started work at the same time (7:59 a.m.) each day, while Engineer D—who had 6 hours' variability—started work at 8:30 a.m., 12:01 a.m., 5:40 p.m., 2:20 a.m., 8:30 a.m., 2:45 a.m., and 7:50 a.m. in a 10-day work schedule.

Figure 3: Actual 10-Day Work Cycles for Engineers With Variable Schedules



	Engineer A	Engineer B	Engineer C	Engineer D	Engineer E
Variability	±0 Hours	±2 Hours	±4 Hours	±6 Hours	±8 Hours
Total Hours Worked	80.0 Hours	48.5 Hours	45.9 Hours	46.1 Hours	45.8 Hours
Average Shift Length	8.0 Hours	9.7 Hours	7.7 Hours	6.6 Hours	5.7 Hours

Variability Causes Fatigue

Circadian rhythms are the inherent biological sleep-wake cycles in a normal 24-hour period. Research has shown that as a result of this biological phenomenon, many types of performance reach minimum levels

Table 1: Allowable Work Schedules for 12-Hours-On, 10-Hours-Off Cycles vs. 10-Hours-On, 10-Hours-Off Cycles

Day	Start/stop time (12-on, 10-off)	Start/stop time (10-on, 10-off)
1	12 a.m. - 12 noon	12 a.m. - 10 a.m.
2	10 p.m. - 10 a.m.	8 p.m. - 6 a.m.
3	8 p.m. - 8 a.m.	4 p.m. - 2 a.m.
4	6 p.m. - 6 a.m.	12 noon - 10 p.m.
5	4 p.m. - 4 a.m.	8 a.m. - 6 p.m.
6	2 p.m. - 2 a.m.	4 a.m. - 2 p.m.
7	12 noon - 12 a.m.	12 a.m. - 10 a.m.

Conclusions

After analyzing human-factor-caused accidents, the time these accidents occurred, and engineers' work schedules, we conclude that the length of the work period allowed by the Hours of Service Act may have little impact on rail safety. Reducing the maximum number of hours allowed per shift from 12 to 10 would at best affect only a small percentage of rail accidents, primarily because only 4.5 percent of the human-factor-caused accidents in 1989 and 1990 occurred after 10 hours in an engineer's shift. More importantly, such a reduction would change the maximum work/off-duty cycle to something less than the current 22-hour cycle, which could increase schedule variability. The resulting variability would be greater over time for engineers who regularly work such cycles and, since humans are biologically adapted to a 24-hour cycle, might actually contribute to increased fatigue and thereby negatively affect performance.

Since engineer fatigue is a factor that can influence performance negatively, we urge caution if any changes to the Hours of Service Act are considered that could introduce even greater engineer schedule variability and thereby increase the potential risk of fatigue, particularly in early morning hours.

Agency Comments

As requested, we did not discuss the findings or conclusions of this report with FRA, the Association of American Railroads (AAR), or BLE. We did, however, discuss our methodology with FRA and AAR, including (1) the source of our accident data, (2) the way we selected the four railroads for review, and (3) the way we selected our sample of engineers and work periods.

We performed our study between August 1991 and March 1992 in accordance with generally accepted government auditing standards. Appendixes I and II contain details of our scope and methodology.

As arranged with your office, unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from the date of this letter. At that time we will send copies to the Presidents, Brotherhood of Locomotive Engineers and Association of American Railroads; the Administrator, Federal Railroad Administration; and other interested parties. Copies will also be provided to others upon request.

Please contact me at (202) 275-1000 if you or your staff have any questions. Major contributors to this report are listed in appendix III.

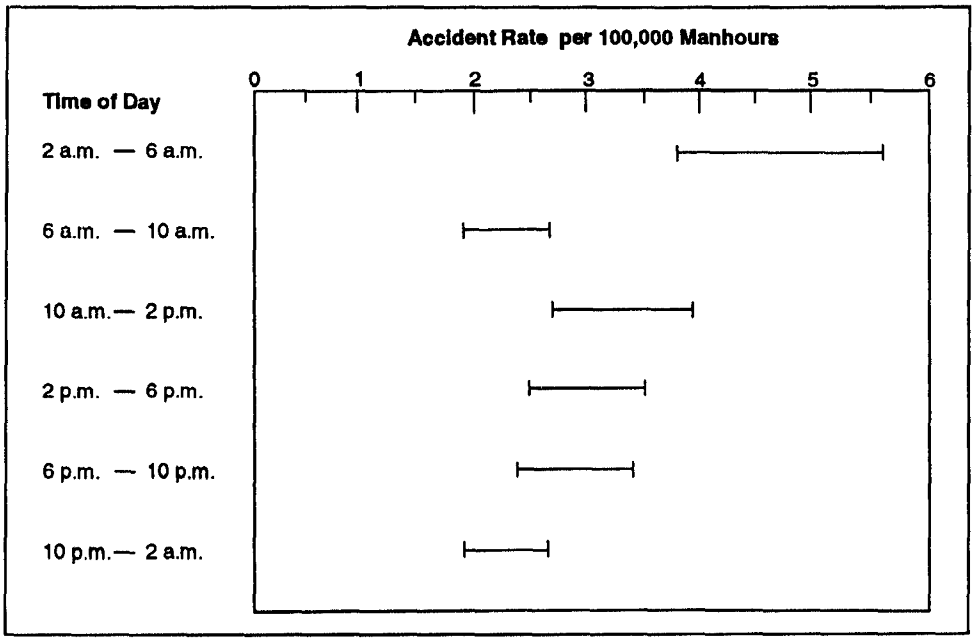
Sincerely yours,

Kenneth M. Mead
Director, Transportation Issues

of effectiveness during early morning hours and that variable work schedules increase worker fatigue, even if the worker receives time to rest following a work period. According to a recent report issued by the Office of Technology Assessment (OTA), variable work schedules can disrupt circadian rhythms. The physiological changes caused by circadian rhythm disruption often interact with other stressors associated with variable work schedules—that is, fatigue, sleep deprivation, and social or family stress—to compound the effects on the performance and safety of the worker. OTA also stated that in some tasks—particularly monotonous ones, such as driving—circadian disruption may decrease performance and compromise productivity and safety.

Research on the relationship between fatigue and accidents for truck drivers and airline pilots indicates that accidents are more likely to occur in early morning hours. We believe that accidents were also more likely to occur in early morning hours for the four railroads we reviewed. We analyzed the accidents by breaking the day into six 4-hour segments to show when the accidents occurred. For the four railroads we reviewed, the highest number of accidents occurred in this time segment in 1990. We also estimate that the accident rate was higher from 2 a.m. to 6 a.m. than at other times. (See fig. 4.)

Figure 4: Accident Rate Estimates—Ranges by Time of Day



Note: Estimates were calculated from 1990 data from the four railroads included in our review.

In addition, we estimate that the start time variability of engineers' work cycles that included hours between 2 a.m. and 6 a.m. averaged between 3.5 and 5.0 hours. Both the number of accidents and the rate of accidents (per 100,000 hours worked) were highest for the four railroads in our sample during this time period. The variability of work cycles that did not include the hours between 2 a.m. and 6 a.m. averaged between 2.8 and 4.3 hours.

Research has shown that highly variable work schedules cause fatigue. FRA and BLE have testified before the Congress that they believe fatigue causes accidents and that fatigue is often cited as a cause of accidents. The research studies we reviewed indicate that a link between fatigue and accidents is strongly suspected. However, other factors may be involved in human-factor-caused accidents, and no researcher has yet found definitive proof that fatigue specifically causes accidents nor measured how fatigue affects the likelihood that accidents will occur.

Because of data limitations, we could not analyze other factors that we believe may also contribute to accidents. We are now analyzing additional, more-comprehensive engineer schedule data from other Class I railroads. When we analyze those data, we will be able to eliminate the sampling error from the statistics of the railroads we reviewed. We will also be able to more accurately determine (1) length and variability of work periods, off-duty periods, and start times; (2) the type of train (yard, through-freight, or other); (3) the location of the accident (yard or nonyard); and (4) the location (i.e., at home or at away stations) of the engineer during off-duty periods. We plan on reporting the results of that analysis at a later date.

Shortening Work Periods May Increase Variability

We analyzed the variability inherent in the current maximum-work/minimum-off-duty periods allowable under the Hours of Service Act. An engineer working a 12-hours-on, 10-hours-off work schedule would have a 22-hour work cycle and experience a variability of 2 hours in every 24-hour period. Shortening the work period from 12 hours to 10 hours would reduce the allowable work cycle to 20 hours but would increase allowable variability within the normal 24-hour cycle to 4 hours. In the most extreme case, such engineers' start times could be 4 hours earlier each time that they came to work, whereas with a 22-hour allowable cycle, their start time could be only 2 hours earlier for each work period. (See table 1.) Shortening the work cycle allowable under the act could therefore increase variability, which, in turn, could increase fatigue in engineers who regularly work such schedules.

Contents

Abbreviations

AAR	Association of American Railroads
ATSF	Atchison, Topeka & Santa Fe Railroad
BLE	Brotherhood of Locomotive Engineers
BN	Burlington Northern Railroad
FRA	Federal Railroad Administration
GAO	General Accounting Office
KCS	Kansas City Southern Railroad
SP	Southern Pacific Railroad

Scope and Methodology

To meet our review objectives, we discussed the implementation of the Hours of Service Act and related safety implications with officials from the Federal Railroad Administration (FRA), the Brotherhood of Locomotive Engineers (BLE), and the Association of American Railroads. We reviewed research studies on the relationship between work schedules, fatigue, and job performance for railroad engineers and other kinds of shift workers.

We analyzed 1989 and 1990 data on human-factor-caused railroad accidents from the railroad accident data base maintained by FRA. We sampled engineers' work schedules for 1990 at six Class I railroads: Atchison, Topeka & Santa Fe (ATSF); Kansas City Southern (KCS); Southern Pacific (SP); Burlington Northern (BN); Grand Trunk Western; and Union Pacific. These were selected to represent a cross section of different-sized railroads. We received data from all six railroads but decided to use data from four (ATSF, KCS, SP, and BN) in this study. Union Pacific provided much more comprehensive data, which we decided to use in follow-on work rather than in this study. We did not receive data from Grand Trunk Western in time to use it for our analyses.

At each railroad, we randomly selected engineers' work schedules, then randomly selected a subsample of 10-day work periods to determine how long engineers typically work in 10 days, how many times engineers typically start work in 10 days, and how much variability existed in work period start times. (See app. II for details of our sampling methodology and the limitations on the uses of our analysis.) Finally, we compared the values computed for the work schedules of railroad engineers with the values expected for the work schedules of hypothetical employees working regularly scheduled, 8 a.m. to 5 p.m., 5-days-per-week schedules.

Reliability of FRA's Accident Data Base

In 1989 we reviewed the accuracy of FRA's accident/injury data base. During that review, we visited FRA's data entry contractor to identify the types of controls used for ensuring the accuracy of its data entry work. We observed that the contractor performed numerous checks to verify its work. These checks of the data, as described to us, appeared adequate to ensure that the data base accurately reflected the information reported by the railroads. Therefore, we did not test the contractor's data entry controls to determine their effectiveness.

Sampling Methodology

To determine (1) railroads' compliance with the Hours of Service Act and (2) characteristics of engineers' work schedules, we used a stratified two-stage cluster sample design. First, we randomly selected 36 engineers on the 1990 roster at the (1) ATSF, (2) KCS, and (3) SP railroads, and 30 engineers at the BN Railroad. Next, we obtained these engineers' work schedules for four randomly drawn 10-day periods in 1990. We reviewed and analyzed the work schedules of the 124 engineers who worked for the sampled railroad more than 40 days in 1990. The total number of engineers in each stratum and the number included in our sample are shown in table II.1.

Table II.1: Total Number of Engineers in Each Stratum and the Number Sampled

	Number of engineers		
Stratum	**In stratum[a]**	**In sample**	**In sample reviewed**
ATSF	2,007	36	35
BN	3,118	30	26
KCS	267	36	36
SP	1,840	36	27
Total	**7,232**	**138**	**124**

[a]Because we did not obtain the work schedules for 14 engineers, our estimates are projected to an adjusted population of 6,301 ± 469 engineers at the four railroads.

Since we used a sample (called a probability sample) of engineers' work schedules to develop our estimates, each estimate has a measurable precision, or sampling error, which can be expressed as a plus/minus figure. A sampling error indicates how closely we can reproduce from a sample the results that we would obtain if we were to take a complete count of the entire universe, using the same measurement methods. By adding the sampling error to and subtracting it from the estimate, we can develop upper and lower limits for each estimate. This range is called a confidence interval. Sampling errors and confidence intervals are stated at a certain confidence—in this case, 95 percent. A confidence interval at the 95-percent confidence level means that, in 95 out of 100 instances, the sampling procedure we used would produce a confidence interval containing the universe value we are estimating. Tables II.2 and II.3 list errors for the estimates shown in the report.

Our sample was not designed to allow us to reliably compare and contrast data from the four railroads. Many differences in railroads would not be detected from a sample such as ours. However, we did observe differences between the railroads in a few instances.[1] In our opinion, the differences we observed would not affect our conclusions. For example, the SP has a longer average work period (9.0 ± 0.6 hours) than either the ATSF (7.5 ± 0.6 hours) or the BN (7.6 ± 0.5 hours).

Table II.2: Sampling Errors and Intervals for Key Estimates From the 1990 Engineer Sample at Four Railroads

			95-percent confidence interval	
Description	**Estimate**	**Sampling error**	**Lower bound**	**Upper bound**
Average work period (hours)	7.87	0.33	7.54	8.2
Average rest period (hours)	31.84	5.59	26.25	37.44
Percentage of engineers' work periods:				
≤ 8 hours	63.37%	6.10%	57.27%	69.47%
≤ 10 hours	82.28%	4.30%	77.99%	86.58%
> 10 and ≤ 12 hours	14.58%	3.76%	10.82%	18.35%
> 12 hours	3.13%	1.69%	1.44%	4.83%
Percentage of engineers' work periods ≥ 12 hours with ≥ 10 hours' rest:				
ATSF[a]	100.00%	0.00%	100.00%	100.00%
KCS	93.65%	5.89%	87.77%	99.53%
SP	99.32%	1.35%	97.97%	100.68%
BN[a]	100.00%	0.00%	100.00%	100.00%
Weighted total	99.43%	0.75%	98.68%	100.18%
Percentage of engineers' work periods:				
0.01 - 2.00 hours	1.01%	0.50%	0.51%	1.51%
2.01 - 4.00 hours	6.36%	2.86%	3.50%	9.22%
4.01 - 6.00 hours	14.89%	3.90%	11.00%	18.79%
6.01 - 8.00 hours	41.11%	6.28%	34.83%	47.39%
8.01 - 10.00 hours	18.91%	3.57%	15.34%	22.49%
10.01 - 12.00 hours	14.58%	3.76%	10.82%	18.35%
> 12 hours	3.13%	1.69%	1.44%	4.83%
Percentage of engineers' work periods with variability of:				
At least 2 hours	53.36%	7.31%	46.05%	60.68%
At least 6 hours	30.46%	4.92%	25.54%	35.37%
Average variability for engineers' work periods with time between 02:00 and 05:59	4.3	0.8[b]	3.5	5.0

(continued)

[1]These differences were observed by finding no overlap between the confidence intervals of estimates for individual railroads.

Description	Estimate	Sampling error	95-percent confidence interval Lower bound	Upper bound
Average variability for engineers' work periods with no time between 02:00 and 05:59	3.6	0.8[b]	2.8	4.3
Percentage of engineers' work periods ≥ 11 and < 12 hours followed by < 10 hours' rest	0.61%	0.42%	0.20%	1.03%
Accidents per 100,000 engineer hours:				
02:00 to 05:59 (2 a.m.-6 a.m.)	4.78	0.96	3.81	5.74
06:00 to 09:59 (6 a.m.-10 a.m.)	2.31	0.38	1.94	2.69
10:00 to 13:59 (10 a.m.-2 p.m.)	3.32	0.58	2.74	3.90
14:00 to 17:59 (2 p.m.-6 p.m.)	3.00	0.46	2.54	3.46
18:00 to 21:59 (6 p.m.-10 p.m.)	2.80	0.55	2.26	3.35
22:00 to 01:59 (10 p.m.-2 a.m.)	2.25	0.38	1.87	2.62

[a]The ATSF sample data showed 10 work periods of more than 12 hours, and the BN sample data showed 29 work periods of more than 12 hours. All these work periods were followed by 10 or more hours of rest.

[b]The sampling error was adjusted to correct a measurement due to rounding in the data.

Table II.3: Sampling Errors and Intervals for Key Estimates for a 10-Day Period From the 1990 Engineer Sample for Four Railroads

Description	Estimate	Sampling error	95-percent confidence interval Lower bound	Upper bound
Average hours worked	50.57	2.85	47.72	53.42
Average hours rested	189.43	2.85	186.58	192.28
Average work periods started	6.43	0.37	6.06	6.79
Percentage of engineers' work schedules:				
< 40 hours	28.3%	5.9%	22.4%	34.2%
≥ 40 and < 60 hours	42.6%	5.5%	37.1%	48.1%
≥ 60 and < 80 hours	20.7%	4.8%	15.9%	25.5%
≥ 80 hours	8.4%	3.8%	4.6%	12.2%
Average number of times an engineer worked 2 consecutive shifts with ≤ 9 hours' rest between shifts.	0.054	0.040	0.014	0.094

Definition of Variability

Variability measures the absolute value of the difference in hours from the beginning of one work cycle to the beginning of the next consecutive work cycle. Variability can range from zero hours (i.e., the start time of one work cycle is exactly the same as the start time of the next consecutive work cycle) to 12 hours (i.e., the start time of the second work cycle is 12 hours different from the start time of the immediately preceding work cycle). We based our measure of variability on work done by the Department of Transportation's Research and Special Programs Administration.

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