Archives of Business Research – Vol. 9, No. 8
Publication Date: August 25, 2021
DOI:10.14738/abr.98.10784.
Tannen, M. B. (2021). The Effect of Diesel Exhaust Exposure on Railroad Worker Health and Mortality: A Survey of Somewhat Competing Evidence. Archives of Business Research, 9(8). 181-189.

The Effect of Diesel Exhaust Exposure on Railroad Worker Health and Mortality: A Survey of Somewhat Competing Evidence

Michael B. Tannen, Ph. D.
School of Business and Public Administration
University of the District of Columbia
4200 Connecticut Ave NW, Washington DC 20008

ABSTRACT

Hazardous work conditions expose employees to health and safety risks, and employers to potentially higher expenses including the possibility of a prolonged series of expensive litigation. Indeed, recognition of this in individual and organized (collective) bargaining over higher pay and health benefit coverage, and of course, government regulation involving improved safety measures and equipment design is common. It is easier for all to deal with such risks when they are recognized, and the extent of that risk known. Often, though, risks may appear uncertain, with contradictory evidence supporting opposing views. Such is the case for the exposure of railroad workers to diesel exhaust, a subject that has been investigated for decades with considerable disagreement. This paper contains a focused survey of published studies in the past thirty-five years using observational data and epidemiology (laboratory studies on animals) to review the extent to which disagreement has or not been abated.

Official concern over the adverse health effects of diesel exhaust on workers was evidenced as least as far back as 1988, when the U.S. Occupational Safety and Health Administration (OSHA) issued a bulletin to its field officers that read "Recent animal studies in rats and mice confirm an association between the induction of cancer and exposure to whole diesel exhaust. … Limited epidemiologic evidence suggests an association between occupational exposure to diesel engine emissions and lung cancer. The consistency of these toxicologic and epidemiologic findings suggest that a potential occupational carcinogenic hazard exists in human exposure to diesel exhaust." [1]In contrast, an article published in the U.S. National Institutes of Health (NIH) National Library of Medicine in 1995 challenged this position based upon epidemiological evidence.[2]An Environmental Protection Agency (EPA) assessment finished in 2002, meanwhile, concluded the issue would require a more complex consideration than might first seem when it reported "long-term (i.e. chronic) inhalation exposure is likely to pose a lung cancer hazard to humans, as well as damage the lung in other ways depending on exposure. Short-term (i.e.,

[1] OSHA "Safety Hazard Information Bulletin on Potential Carcinogenicity of Diesel Exhaust, Memorandum for Regional Administrators, November 30, 1988.
[2] "Diesel engine exhaust and lung cancer: an unproven association," by J.E. Muscat and E.L. Wynder, 1995 Sep;103(9):812-8. doi: 10,1289/chp.95103812.

acute) exposures can cause irritation and inflammatory symptoms of a transient nature, these being variable across the population." [3]

The American Cancer Society website in 2010 emphasized "Men with the heaviest and most prolonged exposures, such as railroad workers, heavy equipment operators, miners, and truck drivers, have been found to have higher lung cancer death rates than unexposed workers."[4] The following year, the U.S. Occupational Safety and Health Administration (OSHA) prominently noted "Diesel exhaust is a pervasive airborne contaminant in workplaces where diesel-powered equipment is used… workers … exposed to diesel exhaust … face the risk of adverse health effects, ranging from headaches and nausea to cancer and respiratory disease. Such workers include … railroad workers…[5] In 2013, OSHA followed up by issuing an alert on its website (still present today), stating "The exhaust from diesel engines contains a mixture of gases and very small particles that can create a health hazard when not properly controlled."[6]

Despite this evidence and the related policy pronouncements, the OSHA webpage noted "There are currently no standards for diesel exhaust as a unique hazard. However, exposures to various chemical components of diesel exhaust are addressed in specific standards for the general industry and shipyard employment."[7] The complexities of diesel exhaust and both known and uncertain interactions with the site-specific environment are presumably responsible for OSHA's reluctance to issue a single diesel exhaust standard. This complexity is explained in the 1988 bulletin, which stated "emissions from diesel engines consist of both gaseous and particulate fractions…. several of which are carcinogens[8].

The OSHA statement draws upon references to laboratory studies of animals. The EPA study, however, is a Health Risk Assessment, implying how individuals located in different vicinities and locations from concentrations of diesel-fueled vehicles and equipment are likely to be affected by carcinogens released in such exhausts, based upon laboratory findings, climatic patterns, and other evidence.

[3] HEALTH ASSESSMENT DOCUMENT FOR DIESEL ENGINE EXHAUST (FINAL 2002), UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, NATIONAL CENTER FOR ENVIRONMENTAL ASSESSMENT, POSTED ON THE EPA WEBSITE JANUARY 6, 2011.

[4] "Diesel Exhaust," American Cancer Society website, posted on November 8, 2010. The American Cancer Society statement draws upon observational evidence on actual workers, but the OSHA statement is references to laboratory studies.

[5] U.S. DEPARTMENT OF LABOR, OCCUPATIONAL SAFETY & HEALTH ADMINISTRATION SAFETY AND HEALTH TOPICS INTERNET PAGE ENTITLED "DIESEL EXHAUST," UPDATED APRIL 22, 2011. QUOTED AS APPEARED ON OCTOBER 2, 2011.

[6] OSHA Hazard Alert (still on website) "The exhaust from diesel engines contains a mixture of gases … (diesel exhaust or DE) and very small particles … (Diesel Particulate Matter or DPM) …that can create a health hazard when not properly controlled."

[7] OSHA, IBID, 2011.

[8] "THE GASEOUS CONSTITUENTS INCLUDE CARBON DIOXIDE, CARBON MONOXIDE, NITRIC OXIDE, NITROGEN DIOXIDE, OXIDES OF SULFUR, AND HYDROCARBONS (E.G., ETHYLENE, FORMALDEHYDE, METHANE, BENZENE, PHENOL, 1,3-BUTADIENE, ACROLEIN, AND POLYNUCLEAR AROMATIC HYDROCARBONS). PARTICULATES (SOOT) IN DIESEL EXHAUST ARE COMPOSED OF SOLID CARBON CORES THAT ARE PRODUCED DURING THE COMBUSTION PROCESS AND THAT TEND TO FORM CHAIN OR CLUSTER AGGREGATES. AS MUCH OF 15% TO 65% OF THE MASS OF PARTICULATE EMISSIONS (SOOT) OF DIESEL ENGINES IS MADE UP OF ORGANIC COMPOUNDS …SEVERAL OF WHICH ARE CARCINOGENS." OSHA, IBID, 1988.

HEALTH RISK ASSESSMENT STUDIES

Several studies of diesel emissions in and near railyards in the United States have focused on particulate matter, not gases [9] A widely-used methodology to assess potential health consequences due to harmful and/or excessive pollution is known as a Health Risk Assessment (HRA). These studies have looked at the railyard's emissions inventory, local meteorological conditions including wind patterns and typical weather, where people live in relationship to the yard, and related factors that can be used to a 'diesel cancer risk' based on the toxicity of diesel emissions.[10]

In 2011, *The Impact Project* [11] issued its policy-related study regarding the adverse health impacts of growing goods movement on persons living near railyards. The piece was written primarily to detail the influence of current and projected railyard pollution on surrounding communities in Southern California, though there is also mention of harmful diesel pollution near railyards in other places–e.g. Chicago, Kansas, and Australia. The Report noted "Of particular concern are diesel particulate emissions, which have been linked to lung cancer and other health effects."[12] These emissions are identified as emanating from a number of sources, namely trucks, cranes, yard hostlers, switch locomotives and line-haul locomotives, other vehicles, and a variety of equipment. The Report emphasizes that passage of thousands of diesel trucks every day through communities on their way to the ports and rail yards impacts health not only in the railyards, but in adjacent communities.

Diesel particulate pollution is a greater health hazard to those who are subject to is concentrated effects on a regular, continuing basis. According to the report, most railyards in the United States already operate round-the-clock and close to capacity, and so the geographically concentrated effect of emissions continues over the entire day. The anticipated substantial growth in railyard traffic due to increased global trade[13] is likely to exacerbate diesel particulate pollution in and near these railyards, with corresponding increased health risks, unless policy is dramatically changed.

[9] The concentration of the latter in a particular location being more affected by varying climatic conditions such as wind.

[10] More specifically, (BNSF, loc. cit. below, p.), "an HRA consists of three major components: the air pollution emission inventory, the air dispersion modeling, and an assessment of associated health risks. The air pollution emission inventory provides an understanding of how the air toxics are generated and emitted. The air dispersion modeling takes the emission inventory and meteorology data such as temperature and wind speed/direction as its inputs, then uses a computer model to predict the distributions of air toxics in the air. Based on this information, an assessment of the potential health risks of the air toxics to an exposed population is performed… Potential cancer risk from a given carcinogen estimated from the health risk assessment is expressed as the incremental number of potential cancer cases that could be developed per million people, assuming the population is exposed to the carcinogen at a constant annual average concentration over a presumed period."

[11] TRACKING HARM: HEALTH AND ENVIRONMENTAL IMPACTS OF RAIL YARDS, THE IMPACT PROJECT POLICY BRIEF SERIES, #1, OCTOBER 2010, BY JOCELYN VIVAR, MARK VALLIANATOS, AND ANDREA HRICKO. THE PROJECT IS A CALIFORNIA-BASED, COMMUNITY-UNIVERSITY COLLABORATION FUNDED BY THE CALIFORNIA ENDOWMENT AND THE KRESGE FOUNDATION.

[12] Ibid, p. 4.

[13] According to the study "recent port projections see a steady growth in cargo growth and is projected to triple by 2030."

This Report, as is the case with HRAs in general, did not present new direct evidence of diesel particulates on individual health, but instead relied upon results from other studies in forming its health-risk projections. In particular, considerable reference was made to a 2007 BNSF-Hobart study (considered more fully later) and the 2005 California Air Resources Board Health Risk Assessment for each of the 18 major California railyards.[14] The impetus for these latter studies followed a 10-year scientific assessment completed in 1998, when the California Air Resources Board identified diesel exhaust particulates (diesel PM) as a toxic air contaminant with potential to cause cancer and produce other health maladies such as respiratory illnesses and increased risk of heart disease. According to the Board, "Population-based studies in numerous cities in the U.S. and around the world demonstrate a strong link between elevated particulate matter levels and premature deaths….many of these studies have linked the health effects to diesel PM… Subsequent research has shown that diesel PM contributes to pre mature death."[15]

The 2005 assessments, collectively, found the railyards responsible for "210 tons of diesel pollution emissions a year, posing a significant public health risk and putting more than 3 million people at elevated risk of cancer."[16] Five of the railyards were identified, individually, as posing "an excessive cancer risk chances of 500-3,300 chances per million, well beyond the level EPA considers acceptable."[17] Much more information and detail is available from the BNSF-Hobart study.

In the BNSF - Hobart Railyard study the Board conducted a voluminous health risk assessment (HRA) of impacts associated with toxic air contaminants emitted in and around the very large BNSF Railway's Hobart Railyard, located in Commence, California.[18] As the report explains "a HRA uses mathematical models to evaluate the health impacts from exposure to certain chemical or toxic air contaminants… HRAs … are estimates for the potential health impacts on a population at large."[19] This particular study focused on railyard emissions (separately and collectively) from locomotives, on-road trucks and other off-road vehicles and equipment used to move cargo. The authors note diesel PM emissions are usually found to be dominant toxic air

[14] "THE COUNTRY'S TWO LARGEST FREIGHT RAILROADS OPERATE PRIMARILY IN THE WESTERN U.S. THESE ARE BNSF RAILWAY COMPANY, WHICH OPERATES 32,000 ROUTE MILES IN 28 STATES AND UNION PACIFIC CORPORATION, WHICH OPERATES 32,100 ROUTE MILES IN 23 STATES. IN CALIFORNIA, THESE TWO RAILROAD COMPANIES OPERATE 18 MAJOR RAIL YARDS."

[15] IBID

[16] Ibid, p. 4.

[17] IMPACT, IBID, P.4.

[18] "Health Risk Assessment for the BNSF Railway Hobart Railyard," California Environmental Protection Agency, Air Resources Board, by Wei Li with contributions from Jing Yuan, Eugene Yang, Chan Pham, Hector Castaneda, et. al., November 2, 2007. BNSF Hobart Railyard is the largest intermodal railyard in the United States focusing on the distribution of international containers. HRAs do not consider health data on specific individuals, but address overall risks for groups of individuals.

[19] THE REPORT CONTAINS WHAT SEEMS LIKE A STANDARD DISCLAIMER "THE RISK ESTIMATES SHOULD NOT BE INTERPRETED AS A LITERAL PREDICTION OF DISEASE INCIDENCE IN THE AFFECTED COMMUNITIES BUT MORE AS A TOOL FOR COMPARISON OF THE RELATIVE RISK BETWEEN ONE FACILITY AND ANOTHER." DESPITE THIS DISCLAIMER, MUCH OF THE TEXT OF THE REPORT, SUCH AS THE SENTENCE QUOTED ABOVE, SEEMS TO IMPLY THAT THE ESTIMATES SHOULD BE TAKEN MORE LITERALLY.

contaminant in and around railyards, and this is found to be so in this study.[20] How far away from railyards are the cancer risks considerable has been a bone of some contention. The HRA 2004 study for UP Roseville Railyard, for example, indicated that cancer risk associated with on-site diesel PM emissions is substantially reduced beyond a one-mile distance from the railyard. The 2007 BNSF-Hobart study stated "the areas with the greatest impact has an estimated potential cancer risk of over 1000 chances in a million, occurring in the area right next to the boundaries of the railyard fence line."[21]

EPIDEMIOLOGICAL STUDIES

Clinical trial evidence on health is seldom available from to human workers regularly exposed to diesel exhaust.[22] One epidemiological study, though, conducted by a team of medical researchers from Imperial College London and the New Jersey School of Public Health[23] focused on the short-term effect of this exhaust on persons with asthma. In this study, the researchers recruited 60 non-smoker adults, approximately half with mild and half with moderate asthma. Each of the subjects walked two hours per day, alternating daily between two locations, one, a busy London street in which the only vehicular traffic was diesel-fueled buses and cabs, and the other through a nearby city park over several months. The conclusions of the study were walking on the city street "induced asymptomatic but consistent reductions in forced expiratory volume…effects were greater in subjects with moderate asthma than mild asthma… our observations serve as a demonstration and explanation of epidemiologic evidence that associates the degree of traffic exposure with lung function in asthma."[24]

In 2012 the U.S. National Institutes of Health published a review of seven of the more recent epidemiology studies on the possible linkage of diesel exhaust and lung cancer.[25] The evidence did not specifically focus on railroad workers. Two concluded "significant exposure-response (E-R) trends between cumulative diesel exhaust and lung cancer were unlikely to be explained by bias or confounding" but the authors of the review article maintained this conclusion (of an apparent cause and effect relationship) was 'non-definitive.' All remaining studies presented some degree of apparent evidence, but were said by the review authors to be flawed because of failure to control for general exposure to air pollution, smoking, and other possible environmental health risks. Specifically, the review authors maintained "weak and inconsistent E-R associations..could be explained by bias, confounding or chance, exposure misclassification, and often inadequate latency." In the authors judgment "the weight of the evidence considered inadequate to confirm the diesel-lung cancer hypothesis."

[20] NON-DIESEL PM TOXIC AIR CONTAMINANTS HAVE LESS THAN A THOUSANDTH OF THE POTENCY WEIGHTED EMISSIONS AS COMPARED TO DIESEL PM.

[21] BNSF-HOBART, IBID, P. 17.

[22] Still, the EPA in 2002 "described the risk of diesel exhaust-related lung cancer based on human epidemiologic studies," according to Garshick, et. al. "Lung Cancer in Railroad Workers Exposed to Diesel Exhaust," Eric Garshick, Francine Laden, Jaime E. Hart, Bernard Rosner, Thomas J. Smith, Douglas W. Dockery, and Frank E. Speizer, Environmental Health Perspectives • VOLUME 112 | NUMBER 15 | November 2004, second page.

[23] "Respiratory Effects of Exposure to Diesel Traffic in Persons With Asthma," James McCreanor, et. al., Imperial College Papers, and Science Daily, also published in The New England Journal of Medicine, December 6, 2007.

[24] Ibid, p. 5.

[25] "Lung cancer and diesel exhaust: an updated critical review of the occupational epidemiology literature," John F Gamble, Mark J Nicolich, Paolo Boffetta, 2012 Aug:42(7):549-98. doi: 10.309/10408444.2012.690725

STUDIES OF RAILROAD WORKERS SURVIVAL AND MORTALITY RATES

Other studies specifically focused on the effect of diesel exhaust on railroad worker health and mortality, based upon observational, not experiment-generated data. These studies may be considered "long-run," even though they actually rely upon cross-sectional data at a point in time. Each study is a snapshot of mortality rates by age at a date, rather than a "panel data" follow-up of the same cohort of individuals (e.g. those newly hired in the same time period), evaluated at several later dates in their careers. Because individuals in this cross-sectional snapshot have worked for railroads for varying number of years, it is possible to relate mortality rates to years of railroad experience and age (not necessarily the same thing), and some other factors, including occupational group (available in the data) and cigarette smoking (asked of friends and relatives of those in the sample who are deceased).

Major advantages of these studies are that they consider a substantial period of worker's lives,[26] allow for consideration of accumulated diesel exhaust effects, reflect actual work-life situations, and cover a substantial number of individuals. But their design also presents greater statistical challenges than experimental epidemiological studies in ferreting out what is controlled from what cannot be controlled for in a non-experimental situation.[27]

None of the results in these studies is thoroughly definitive, but the statistical methodology used has been improved over time, yielding generally consistent results. These studies provide a body of consistent evidence indicating that railroad workers who have been regularly exposed to diesel fumes over decades are more likely to die from lung cancer than either other railroad workers or the general population, by a substantial margin. Recent research on chronic pulmonary diseases by some of the same authors, moreover, demonstrates that lung cancer is not the only disease or malady that can be linked, statistically, to diesel emissions.[28]

[26] THE DATE AT WHICH WORKLIFE AND DIESEL EXPOSURE BEGIN IN THESE U.S. STUDIES IS 1959. BY WAY OF BACKGROUND, IN 1946, 10% OF THE LOCOMOTIVES IN SERVICE WERE DIESEL, BUT BY 1959, THE TRANSITION TO DIESEL ENGINES WAS NEARLY COMPLETE, AT 95%.

[27] Clinical trials, properly conducted, are truly "experimental" in that they rule out systematic confounding influences from other possible causes of a disease or mortality, usually by random assignment of subjects to the suspected hazard. Clinical trials of exposure to diesel exhaust with random assignment of individuals, observed over a long-enough period of time to satisfactorily track the progression of a disease have not yet been undertaken. Observational studies are based upon existing data sets are not truly experimental because the possibility of confounding effects can, at best, be partly controlled for. Such studies have difficulty with satisfactorily controlling, for example, a type of selection bias known as the "healthy worker effect." This may be interpreted as the phenomenon of employed persons to be healthier than unemployed persons who are comparable on other characteristics. Continuing employed persons, therefore, are less likely to succumb to a toxic substance, yielding the surprising and probably misleading conclusion that those who are exposed longer have lower mortality rates.

[28] ACCORDING TO A MARCH 2011 POLICY PAPER ["GLOBAL TRADE IMPACTS: ADDRESSING THE HEALTH, SOCIAL AND ENVIRONMENTAL CONSEQUENCES OF MOVING INTERNATIONAL FREIGHT THROUGH OUR COMMUNITIES"] WRITTEN BY AUTHORS FROM OCCIDENTAL COLLEGE &UNIVERSITY OF SOUTHERN CALIFORNIA, [P. 15], "U.S. RAILROAD WORKERS HIRED AFTER THE INTRODUCTION OF DIESEL LOCOMOTIVES HAD A 2.5% INCREASE IN CHRONIC OBSTRUCTIVE PULMONARY DISEASE (COPD) MORTALITY RISK FOR EACH ADDITIONAL YEAR OF WORK IN A DIESEL-EXPOSED JOB. REF: HART JE, LADEN F, EISEN EA, SMITH TJ, GARSHICK E. CHRONIC OBSTRUCTIVE PULMONARY DISEASE MORTALITY IN RAILROAD WORKERS. OCCUP ENVIRON MED 2009;66(4):221-6."

Over the 1984-2010 period, teams of researchers affiliated with prestigious medical schools, hospitals, and schools of public health published papers on the effect of diesel exhaust exposure on railroad worker mortality. In 2004, one such paper noted that other authors had identified more than 35 studies of workers exposed to freshly generated diesel exhaust that demonstrated an excess lung cancer risk in the range of 20-50%.[29]

The reason for the continuing series of studies, it was noted,[30] was to fill an important gap, as prior studies lacked detailed occupational histories or follow-up over enough years to satisfactorily assess diesel exposure risk in the railroad industry. Several of these studies specifically addressed railroad workers in the United States using records obtained from the Railroad Retirement Board, augmented by other data sources, such as Health Care Financing Administration records, death certificates, and the National Death Index (identifying principal cause of death).

Thus, in 1984, Schenker, et. al., a team of medical researchers from Harvard Medical School and Harvard School of Public Health, published the results of their pilot study of railway worker mortality in the United States.[31] It was based upon a modest sample of data from the records maintained by the Railroad Retirement Board, with a stated purpose of determining whether preliminary and tentative findings so generated were sufficiently promising to warrant a larger investigation. The sample in this "pilot study" consisted of about 2500 white males, aged 45-64, each with 10 or more years of railway service by 1967. The authors designated job classifications as either likely or not likely to be regularly subject to diesel exposure. Cause-specific mortality, i.e., death from specific cause, was determined for those who had died by 1979. While overall mortality rates (standardized for age) in this sample were similar to U.S. national averages (no statistically significant differences), the principal finding was that subjects believed to be regularly exposed to diesel exhaust had a 42% higher mortality rate than others in the sample, and this finding was statistically significant (5% level).

Additional results in this study were based upon a more sophisticated statistical methodology, the widely-used proportional hazards model, also produced estimates consistent in direction and magnitude with this finding. These latter results, however, were not statistically significant (5% level), which the authors suggested could possibly be attributed to the smallish sample size, lack of controls for other relevant factors,[32] and/or insufficient time elapsed to diesel exposure for many members of the sample.

[29] ERIC GARSHICK, FRANCINE LADEN, JAIME E. HART, BERNARD ROSNER, THOMAS J. SMITH, DOUGLAS W. DOCKERY, AND FRANK E. SPEIZER, ENVIRONMENTAL HEALTH PERSPECTIVES • VOLUME 112 | NUMBER 15 | NOVEMBER 2004, P. 1539.

[30] Ibid.

[31] "Diesel exposure and mortality among railway workers: results of a pilot study," M B Schenker, T Smith, A Munoz, S Woskie, AND F E Speizer, British Journal of Industrial Medicine 1984;41:320-327.

[32] THE AUTHORS BELIEVED, FOR EXAMPLE, THAT INDIVIDUALS CONSIDERED WERE LIKELY TO HAVE SIMILAR LIFESTYLES BECAUSE THEY CAME FROM THE SAME SOCIOECONOMIC STRATA, BUT ACKNOWLEDGED THERE WAS NOT A STATISTICAL CONTROL FOR POSSIBLE DIFFERENCES IN CIGARETTE SMOKING.

Several other studies appeared in the next few years, using the same Railroad Retirement master datafile.[33] In 2004, a published study by Garshick, et. al.,[34] noted that "few studies had occupational histories and follow-up over enough years to assess risk because lung cancer may develop only after many years of exposure and years of latency." [35] This work again relied upon Railroad Retirement records (the same sample used in the 1987 Garshick, et. al. study,[36] employed a much larger random sample than the 1984 study noted above (about 55,000 observations here), and measured and compared lung cancer mortality among U.S. railroad workers between 1959-1996, a 38 year period. There were a number of statistical controls and methodological improvements made in this study as compared to prior work. The principal finding of this study was that lung cancer mortality was elevated in jobs associated with work on trains powered by diesel locomotives. Specifically, elevated-mortality rates were found for engineers or conductors, as compared to presumably non-exposed office workers. The magnitude of the difference was consistent with what had been found in previous studies. These results were statistically significant, though some unexpected results appeared (the highest relative mortality difference by occupation appeared for men 40-44 years old; the lowest for men over age 60.)

A newer study (2009)[37] of the same data used a different kind of statistical analysis, multiple regression threshold analysis, and an improved (augmented) data set to reexamine the same issues. Though far less used in health studies than conventional survival analysis, multiple regression has the advantage of being able to simultaneously control for the influence of several factors at once. The findings from this analysis are based upon individual observations, not data grouped by categories in which information on factors not used in grouping is lost. The data set used in previous studies by Garshick, et. al., was augmented with new information on smoking behavior and likely exposure to asbestos before it was examined using this new methodology.

The advantages of simultaneously controlling for several factors is obvious from the list of variables identified by the authors : "The main explanatory variables for our analysis include age at death…,year the subject first joined the railroad…, year of retirement from the railroad …, years of work as an engineer or brakeman …, years of unexposed work, i.e., not as an engineer or brakeman …, years in retirement before death … and indicator variables for 'ever worked as engineer or brakeman'…, 'ever worked in a railroad shop'…, 'ever smoked cigarettes'…and 'ever exposed to asbestos'...The work history variables allow the experience of each subject to be divided into years before joining the railroad, years of work in each job category, and years of retirement before death. We measure each subject's history from birth."[38]

[33] For example, Garshick, et. al., 1987, "A Case-Control study of lung cancer and diesel exhaust exposure in railroad workers, American Review of Respiratory Diseases, 137(4): 820-825.

[34] GARSHICK (2004), IBID.

[35] Ibid, second page of report.

[36] Improvements in the accuracy of mortality and other information were made from previous studies using the same data. Records originally obtained for the sample of workers in 1980 were augmented by follow-up information.

[37] "A case–control study relating railroad worker mortality to diesel exhaust exposure using a threshold regression model," by Mei-Ling Ting Lee,*, G.A. Whitmore, Francine Laden,, Jaime E. Hart, and Eric Garshick, a National Institutes of Health author manuscript published in *J Stat Plan Inference,* February 13, 2009.

[38] Ibid, p. 3.

The major finding of the study was identified as follows: "Jobs with regular exposure to diesel exhaust had a survival pattern characterized by an initial delay in mortality, followed by a rapid deterioration of health prior to death."[39] Some of the puzzling findings of previous studies, such as the conflicting evidence on whether time exposed to diesel exhaust mattered, were cleared up by using this new methodology and augmented data (it does).[40]

CONCLUDING REMARKS

In this survey, key findings of studies exploring the linkage between diesel exhaust (fumes and particulates) and elevated cancer and pulmonary disease risk for railroad workers have been explored. Results based upon two different methodological approaches (observational data analysis using multivariate or cohort statistical techniques versus epidemiological studies) have been examined and compared. Observational studies, collectively, are remarkably consistent in their findings of a harmful link despite improvements in study methodology and available data spanning several decades. This link is more pronounced for workers with longer duration of railroad employment, and for specific railroad occupations that are regularly exposed to diesel exhaust. Improvements in diesel engine design over the years has resulted in newer models producing less hazardous emissions, but much of the railroad industry continues to rely upon the use of older engines. The apparent health risk to railroad workers continues.

The evidence has been far less conclusive for epidemiological studies, however. Several have uncovered no statistically significant relationship between diesel exhaust and worker cancer, while others have otherwise been described as methodologically flawed. The gap in conclusions, therefore, between observational studies and epidemiology studies persists.

[39] Ibid, p. 1.

[40] A more recent study relied upon a different methodology but reached the same conclusion (see *Vermeulen R, Silverman D, Garshick E, Vlaanderen J, Portengen L, Steenland, Exposure-response estimates for diesel engine exhaust and lung cancer mortality based on data from three occupational cohorts. Occupational Environ Med 2014; 71 Suppl 1:A47.*