NIST Technical Note 2078

The Economics of Firefighter Injuries in the United States

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The Economics of Firefighter Injuries in the United States

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Abstract

This report identifies, summarizes, and evaluates the available data and the literature describing the economic costs associated with non-fatal firefighter injuries, illnesses, health exposures, and occupational disease ('health outcomes') resulting from line-of-duty activities. National firefighter non-fatal health outcome data, published by the National Fire Protection Association (NFPA), U.S. Fire Administration (USFA), and the Bureau of Labor Statistics (BLS), are compared and contrasted in terms of coverage and detail provided. A survey of the economic injury literature is used to estimate the direct and indirect costs of non-fatal health outcomes. A matching procedure is introduced to combine the statistical and economic data to produce an annual estimate of firefighter non-fatal health outcome costs. The conclusion provides a discussion of the current measurement challenges that prevent a complete and thorough accounting of those costs associated with non-fatal firefighter injuries, illnesses, health exposures, and occupational disease. Data gaps exist, largely due to delays between exposure and the onset of symptoms, in capturing the incidence and economic consequences associated with firefighter cancer and other occupational diseases, including post-traumatic stress injuries. The estimated cost of firefighter injury is estimated to range between $1.6 billion and $5.9 billion annually. This cost result in a loss equivalent of approximately $50 000 to $200 000 per fire department per year or $1500 to $5500 per firefighter per year.

Key words

Costs; economics; exposure; fire; firefighter; illnesses; injury; losses;

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1. Introduction

In 2016, U.S. fire departments received 35.3 million calls, of which 1.8 million were for fire and hazardous materials incidents, while another 22.8 million were requests for medical aid (National Fire Protection Association, 2019). Over one million firefighters responded to these calls, split between career (33%) and volunteer (67 %) (Evarts and Stein, 2019). The health risks faced by firefighters, associated with response, suppression, rescue and aid related activities, are considerable. In 2016, 69 firefighters died on-duty and another 62 085 suffered injuries requiring treatment by a medical professional. While the number of fire incidents and injuries has been trending downward, the decline in non-fatal injuries has been slower. Although there is a lengthy literature that describes the cause, nature, and severity of firefighter injuries, less is known about the economic impact non-fatal injuries.

The economic consequences of injuries go beyond the costs associated with direct medical expenses and workers compensation. Significant indirect costs include lost productivity and diminished quality of life. Further, because fire departments are funded from taxes and other public sources of revenue, and the benefits of their services are a common good, firefighter injuries represent a societal cost borne by many. Activities that prevent and mitigate firefighter injuries yield economic benefits to the community. Additionally, focusing on the economic costs of injuries, as oppose to the number of injuries, should provide insight into the value of risk reduction efforts that do not eliminate, but reduce injury severity and downtime.

This report identifies, summarizes, and evaluates the available data and literature describing the economic costs associated with non-fatal firefighter injuries, illnesses, health exposures, and occupational disease ('health outcomes') resulting from line-of-duty activities. The objectives of the analysis described was to (1) characterize the annual number and types of firefighter injuries; (2) research direct and indirect costs of these injuries born by firefighters and their communities; (3) establish and utilize a framework to assess and benchmark these costs; and (4) identify current data shortcomings or gaps.

National firefighter non-fatal health outcome data, published by the National Fire Protection Association (NFPA), U.S. Fire Administration (USFA), and the Bureau of Labor Statistics (BLS), are compared and contrasted in terms of coverage and detail provided. A survey of the economic injury literature is used to estimate the direct and indirect costs of non-fatal health outcomes. A matching procedure is introduced to combine the statistical and economic data to produce an annual estimate of firefighter non-fatal health outcome costs. The conclusion provides a discussion of the current measurement challenges that prevent a complete and throughout accounting of those costs associated with non-fatal firefighter injuries, illnesses, health exposures, and occupational disease. Data gaps exist, largely due to delays between exposure and the onset of symptoms, in capturing the incidence and economic consequences associated with firefighter cancer and other occupational diseases, including post-traumatic stress injuries.

Section 2 presents the statistical data sources describing firefighter injuries, illnesses, health exposures, and occupational disease that are currently tracked annually for the United States. Included is a discussion of the details provided in these datasets, which include information related to firefighter characteristics, activity at time of the incident, and the type, cause, severity of the health outcomes.

Section 3 presents literature describing the economic burden of injuries, illnesses, health exposures, and occupational disease focused on different populations including: (1) general public; (2) occupationally-related; (3) firefighter-specific. The economic burden includes direct (e.g., lost wages) and indirect sources (e.g., reduced workplace productivity).

Section 4 illustrates in detail a commonly-used economic approach for valuing the economic burden resulting from occupational injury and illnesses. Formulas depict the computations used to calculate costs associated with: (1) medical and emergency services; (2) lost wage and household work; (3) legal and administrative costs; (4) workplace disruption; and (5) reduced quality of life.

Section 5 introduces a matching procedure used to map the health outcome statistical data with the economic literature on cost estimates. The matching procedures yielded a range of annual total costs estimates of firefighter injuries, illnesses, health exposures, and occupational disease for the United States.

Section 6 discusses current data challenges and gaps associated with measuring the economic burden of firefighter injuries, illnesses, health exposures, and occupational disease. The topics included are cancer, mental health, other occupational diseases, and firefighter productivity.

Section 7 provides a summary and discussion.

2. Firefighter Injuries, Illnesses, Health Exposures, and Occupational Disease Statistics Literature & Data Review

Three national data sources exist that provide statistics quantifying firefighter injuries, illnesses, and health exposures. While these three national data sources provide estimates of these incidents, they measure different things. (There are other relevant data sources,[1] but the three described below are the only annually produced with nationwide representation.)

2.1. National Data Sources and Number Of Injuries

The National Fire Protection Association (NFPA) produces annual estimates of firefighter injuries, illnesses, and exposures. The latest report, *United States Firefighter Injuries—2016* (Haynes and Molis, 2017), is based on the NFPA *2016 National Fire Experience Survey*. The survey draws from a set of fire departments from across the country, stratifying departments by the size of their protected population, and included all departments with a population of 5000 or larger. Departments with smaller populations (<5000) were randomly sampled. In 2016, 20 490 departments were sampled, resulting in a 14 % response rate (Haynes and Molis, 2017). Respondents represented approximately 9 % of all departments.

Based on 2769 fire department responses, NFPA estimates 62 085 injuries, 9275 exposures to infectious disease, and 36 475 exposures to hazardous conditions to firefighters were reported by fire departments in 2016.

NFPA defines injury as:

[1] E.g., International Association of Fire Fighter *Annual Death and Injury Survey*, National Institute for Occupational Safety and Health (NIOSH) *National Electronic Injury Surveillance System (NEISS-Work)*, Agency for Toxic Substances and Disease Registry (ATSDR) *Hazardous Substances Emergency Events Surveillance (HSEES)*. For more information see: Houser et al. (2004).

"*Physical damage suffered by a person that requires (or should require) treatment by a practitioner of medicine (physician, nurse, paramedic, EMT) within one year of the incident (regardless of whether treatment was actually received), or that results in a least one day of restricted activity immediately following the incident*." (Haynes and Molis, 2017, pg. 23)

The U.S. Fire Administration's (USFA) National Fire Incident Reporting System (NFIRS) includes incident-based data, which includes data on firefighter casualties. Over one-million fires are reported to NFIRS each year, representing about 75 % of all reported fires, and covering 24 000 fire departments.[2] While NFIRS is the most comprehensive database of fire incidents for the US, it represents only a partial census of all reported fire incidents, and therefore, is not necessarily a representative sample. Beside its incompleteness, systematic missing and misreported incident-level data entries exist. Any annual variation in the extent of the partial reporting or completeness of data entry creates challenges in tracking NFIRS-based fire statistics over time. (The data may not be directly comparable from year-to-year.) However, it includes incident detail found nowhere else.

The NFIRS Fire Service Casualty Module is used to account for deaths, injuries, and health exposures. NFIRS contains 6570 instances of non-fatal firefighter injuries requiring at least treatment by a physician in 2016. NFIRS (2015)[3] and NFPA (2017) use the same definition of injury. First aid treatment account for 1971 of instances, while health exposures account for another 7447 instances in NFIRS. Exposure is defined as the "Potential for injury or death to humans (pg. C-3).[4]

The Bureau of Labor Statistics (BLS) surveys a sample of U.S. employers in their *Survey of Occupational Injuries and Illnesses* (SOII).[5] The SOII is an annual survey of workplace injuries and illnesses. The survey includes a sample of about 200 000 establishments.[6] It does not include self-employed establishments, however, and only paid employees are included. SOII uses a two-stage process to create its sample. Establishments are selected using stratification to (1) account for industry, ownership, and employee size, and (2) account for cases involving only lost work days. Establishments are required by law to complete and submit their surveys.

The BLS SOII estimates 19 200 nonfatal injuries and illnesses (injuries cannot be separated out) for the fire protection industry (NAICS 92216). A reportable (nonfatal) injury or illness is defined by OSHA (2018)[7] as:

- *"Any work-related injury or illness that results in loss of consciousness, days away from work, restricted work, or transfer to another job.*
- *Any work-related injury or illness requiring medical treatment beyond first aid.*
- *Any work-related diagnosed case of cancer, chronic irreversible diseases, fractured or cracked bones or teeth, and punctured eardrums.*

[2] See: https://www.usfa.fema.gov/data/nfirs/about/index.html
[3] National Fire Incident Reporting System, *Complete Reference Guide*, July 2015.
[4] Presumably this is the same definition used by NFPA.
[5] See: https://www.bls.gov/respondents/iif/
[6] https://www.bls.gov/respondents/iif/faqs.htm#14
[7] https://www.osha.gov/recordkeeping/

- *There are also special recording criteria for work-related cases involving: needlesticks and sharps injuries; medical removal; hearing loss; and tuberculosis."*

Some differences are apparent in comparing the injury estimates across the three data sources. NFPA estimates fire departments responded to 1 342 000 fire incidents in 2016,[8] while NFIRS reports 1 153 060. NFIRS accounts for 86 % of all fires reported by NFPA, but only 14 % of the fire injuries and 16 % of exposures. NFPA reports that of the 62 085 estimated injuries, 19 050 injuries resulted in lost work days. While this closely agrees with SOII estimates (19 200), the SOII only includes paid employees, and not volunteers. NFIRS data indicates that 17 % of injured firefighters with a known affiliation were volunteer firefighters. Therefore, each data system captures different aspects of the US fire service and none of them overlap with great significance.

Table 1 provides a categorization of the data found in the three data sources, demonstrating how the sources compare in terms of included detail, including the data sampling approach. Other than *Sample* and *Number of Injuries*, Table 1 groups data included in each of the data sources into:

- *Firefighter Characteristics* – factors specific to the firefighter
- *Cause of Injury* – factors describing the cause of the injury
- *Type of Injury* – factors describing the nature of the injury
- *Activity* – factors describing the activity and location at the time of injury
- *Severity* – factors indicating the consequence of the injury

2.1.1. Firefighter Characteristics

NFIRS reports the mean age of an injured firefighter was 39.4 years old, and 83 % of them were career firefighters. Over 64 % of injured firefighters did not respond to another incident within the previous 24 hours. However, 30 % of injured firefighters responded to 1 - 5 previous incidents. Eleven percent of those injured identified themselves as 'ill or injured' or 'fatigued' at the time of the injury.

SOII provides information on age, length of service with the employer, and hours worked prior to injury for career firefighters who experienced lost work time. In 2016, 36 % were between the ages of 35 and 44, followed by 45 to 54 (26 %) and 25 to 34 (25 %). The majority (77 %) of injured firefighters had more than five years of service with the department. New employees (less than a year) made up 6 %. One-third of injuries were not reported with the number of hours worked prior to the injury. Of those reported, 19 % occurred two to four hours after the start of work. Sixty-one percent of injuries occurred within the first eight hours of work. Sixteen percent occurred after eight or more hours. Nearly 13 % of injuries with lost worktime resulted in cases with job transfer or restriction.

NFPA does not provide statistics on the characteristics of injured firefighters.

[8] NFPA Fact Sheet: An Overview of the U.S. Fire Problem. https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics/Fact-sheets/FireLossFacts.pdf

2.1.2. Cause of Injury

NFPA provides cause of injury of those injuries that occurred at the fireground. (Fireground injuries are shown to account for 39.2 % of all injuries.) The primary causes are overexertion and strain (27.1 %), followed by falls, jumps, and slips (21.0 %), and other (16.4 %).

NFIRS reports overexertion and strain (30 %) and exposure (19 %) as the largest causes of firefighter injury resulting in lost days (see Figure 1). Of those factors contributing to injury, other (31 %), fire progress (12 %), uneven surface (10 %), slippery or uneven surfaces (7 %), and icy surface (6 %) as the top factors.

SOII reports over half (52 %) of injuries and illnesses resulting in lost workdays occurred due to overexertion and body 'reaction.' Slips, trips, and fall are second at 21 %.

Table 1. Categorization of data found in NFPA, NFIRS, and SOII national data products.

Category	NFPA	NFIRS	SOII
Sample	Survey: *US Fire Departments* (n = 2769)	Partial Census: *US Fire Department Reported Casualties* (n = 16 022)	Survey: *US Employers* (n ≅ 200 000)
Number of Injuries	Number of Injuries and Exposures	Number of Injuries and Exposures	Number of Injuries, Illnesses, Exposures
Firefighter Characteristics		Affiliation Age Physical Condition Just Prior to Injury Responses	Affiliation (Paid-Only) Age Length of Service with Employer Hours Worked
Cause of Injury	Cause of Injury	Cause of Firefighter Injury Factor Contributing to Injury	Event or Exposure
Type of Injury	Nature of Injury	Primary Apparent Symptom Object Involved in Injury Primary Body Part Injured	Nature of Injury, Illness Primary Source of Injury, Illness Secondary Source of Injury, Illness Part of Body Affected
Activity	Type of Duty	Activity at Time of Injury Where Injury Occurred Specific Location Where Injury Occurred	
Severity	Lost Time	Severity (*minimum is first aid treatment*) Taken To	Number of Days Away from Work Cases with Job Transfer or Restriction

Definition of injuries, illnesses, and exposures vary and are defined in section 2.1.

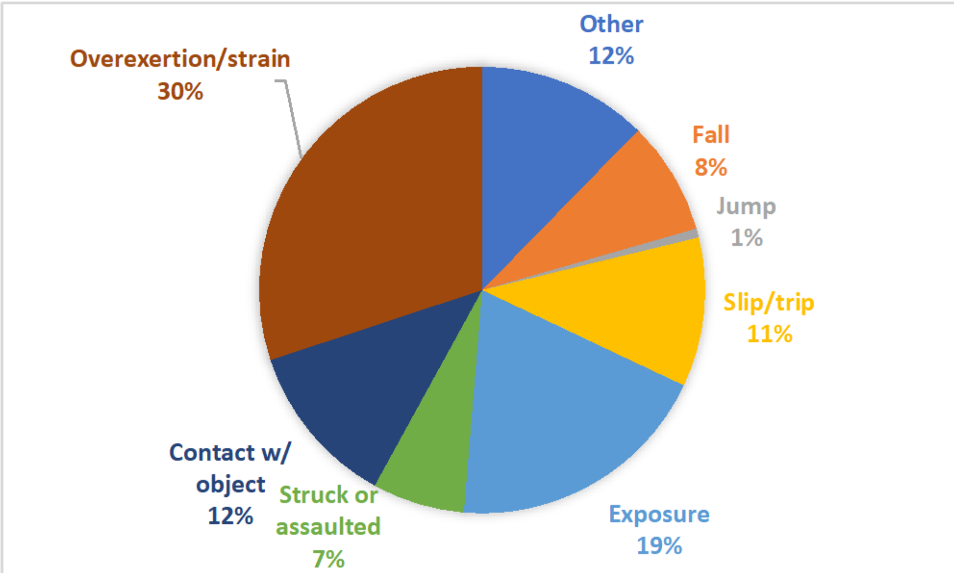

Figure 1. Percent of injuries by physical condition at time of injury (Source: Haynes and Molis, 2017).

2.1.3. Type of Injury

The leading types of injuries are shown, by data source, in Table 2.

NFPA finds strain, sprains, and muscular pain were the leading type (nature) of injury (52.6 %), followed by wound, cut, bleeding, and bruise (15.2 %), and other (14.7 %). (The relative ranking holds regardless of type of duty.)

NIFRS reports strains or sprains (31 %), pain only (17 %), cut or laceration (8 %) were the top three primary apparent symptoms of injured firefighters. Of all injuries, hand and finger (12 %), knee (9 %), back (8 %), and shoulder (8 %) were the most often primary body part injured. The leading primary objects involved in the injury included other (12 %), tools and equipment (9 %), charged hose (7 %), fire department vehicle or apparatus (7 %), and victim (7 %).

SOII shows that sprains, strains, and tears (53 %) were the leading nature of injury or illness. Other types (17 %) and soreness and pain (15 %) round out the top three. Both the primary and secondary source of injury or illness were reported. Beside other (29 %), worker motion or position (22 %), health care patient (12 %), and floors, hallways, and walkway surfaces (12 %) were the dominant sources. Of the secondary sources, ice, snow, and sleet (29 %) were followed by highway and motorized vehicles (25 %) and tools and equipment (12 %). Of the parts of the body affected, trunk (27 %) and lower extremities (24 %) were the most frequently injured. Of these, back (19 %) and knee (10 %) were the most common.

Table 2. Leading types of injuries by data sources.

Type of Injury	NFPA	NFIRS	SOII
Primary Type	Strains, Sprains, Muscular Pain (52.6 %)	Strains or Sprains (31 %)	Sprains, Strains, Tears (53 %)
Secondary Type	Wound, Cut, Bleeding, Bruise (15.2 %)	Pain Only (17 %)	Other (17 %)
Tertiary Type	Other (14.7 %)	Cut or Laceration (8 %)	Soreness and Pain (15 %)

2.1.4. Activity

NFPA shows that the majority of injuries occurred at the fireground (39 %), followed by non-fire emergencies (21 %) and other, on-duty calls (18 %). As mentioned above, the relative ranking of the nature (type) of injury is fairly consistent across type of duty categories.

NFIRS reports that firefighters were involved in providing EMS care (14 %), handling charged hoselines (11 %), extinguishing fires (9 %) as the top three activities at the time of their injury. The majority of injuries occurred outside at scene (33 %) or at scene, inside the structure (42 %). (The specific locations listed are largely identical to the general location listed.)

SOII does not contain any information regarding the type of activity occurring at the time of injury.

2.1.5. Severity

NFPA provides the number of injuries with lost worktime, which offers a measure of the severity of the injury sustained. Of all reported injuries, 30.6 % resulted in lost worktime.

NFIRS data show that 47 % of injuries were report-only or exposures (Figure 2). Another 12 % of injuries required first aid only, and 17 % were treated by a physician, but resulted in no lost worktime. Of the injuries requiring treatment, 50 % did not require transportation or ambulatory services, while 36 % required transport to a hospital.

SOII tracks the number of days away from work and cases with job transfer or restriction. The median number of days away from work is 15 days, with 31 % of injuries resulting in 31 or more days away (Figure 3). Ten percent of injuries resulted in a single day lost.

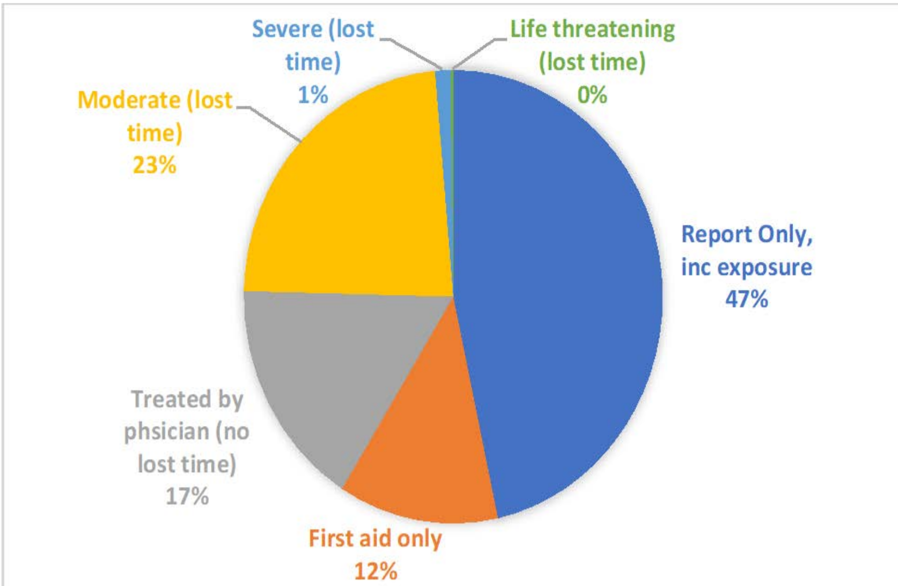

Figure 2. Percent of injuries by severity (Source: Haynes and Molis, 2017).

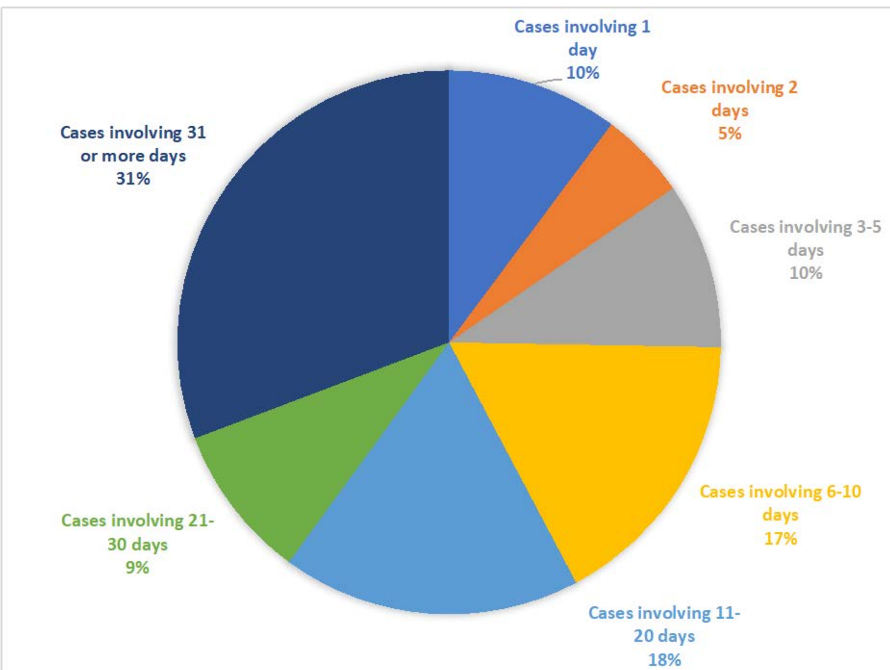

Figure 3. Percent of nonfatal occupational injuries and illnesses involving days away from work by number of days away from work (Source: SOII).

3. The Economics of Firefighter Injuries, Illnesses, Health Exposures, and Occupational Disease Statistics: Literature & Data Review

This section summarizes key studies in the literature related to economic costs of illnesses and disease. It is organized into studies that focused on (1) all injuries and illnesses, (2) occupational injuries and illnesses, and (3) firefighter injuries and illnesses. In addition, a section on productivity impacts is included.

3.1. Economic Burden of Injuries and Illnesses

Rice et al. (1985) estimated the economic burden resulting from illness, disability, and death in 1980. They estimated the burden to be $1.4 billion in total, with $672.2 million attributed to direct costs, $216.6 million for morbidity-related (due to injury or illness) indirect costs, and $560.7 million for mortality-related (due to premature death) indirect costs (2018 dollars). Indirect costs account for lost work days. Figure 4 shows indirect costs as a percent of direct costs, by diagnosis, adapted from Rice et al. (1985), Table 1. Unlike mortality costs, morbidity costs tend not to be as large as direct costs, with infectious and parasitic diseases being closest (96 % of direct).

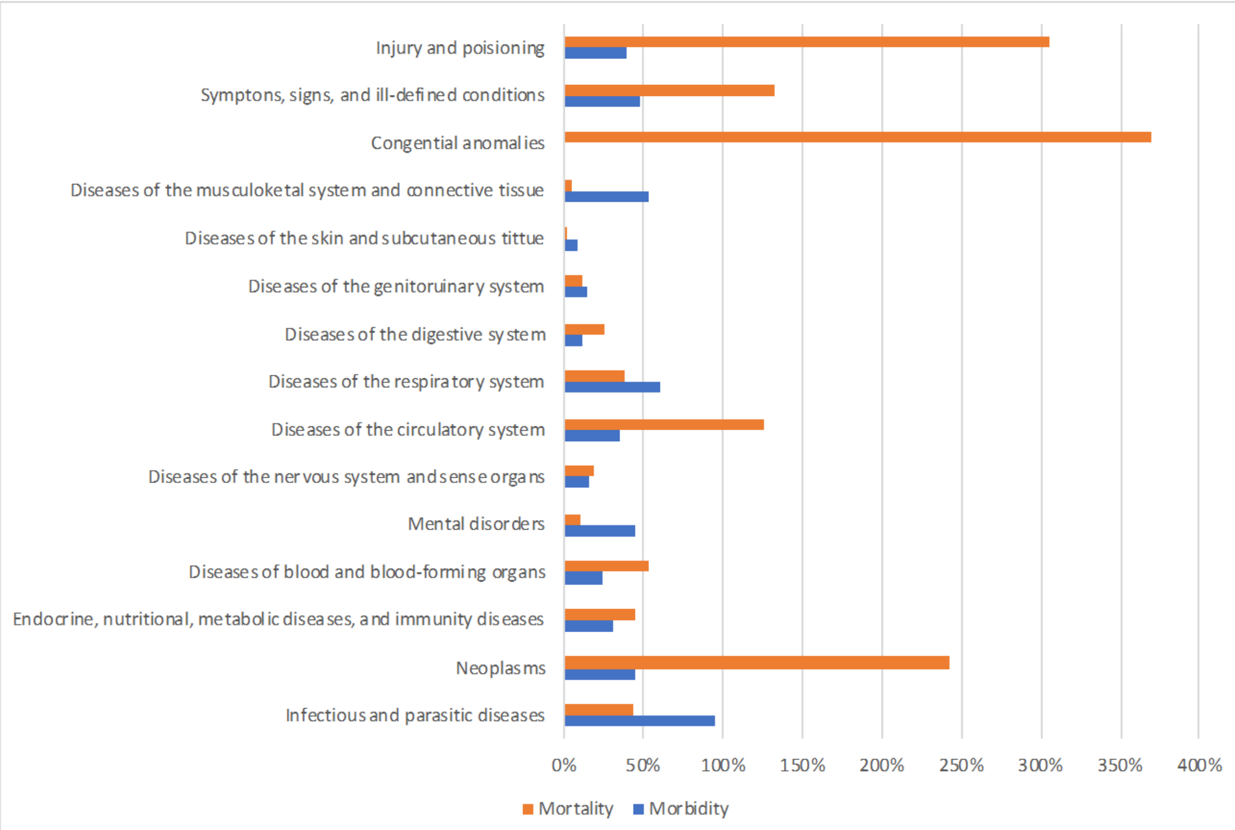

Figure 4. Mortality and morbidity indirect costs as a percent of direct costs, by diagnosis, adapted from Table 1 of Rice et al. (1985).

Corso et al. (2006) estimated the lifetime costs of all fatalities and injuries (including occupational) occurring in 2000 at $596 billion, with $117 billion for medical treatment and $479 in lost productivity (2018 dollars) with 18 % of the US population treated. Incidence and medical cost data were obtained from the National Vital Statistics System, Medical Expenditure Panel Survey, Healthcare Cost and Utilization Project-National Impatient Sample, and the National Electronic Injury Surveillance System. The authors found the incidence rate was 15 % lower in 2000 than 1985 with the largest reduction experienced by those younger than 45.

Table 3 presents the per incidence lifetime injury costs by injury mechanism, which was adapted from data provided in Table 3 of Corso et al. (2000). Of the injury mechanisms likely to affect firefighters drowning injuries were the costliest at $774 145 per incidence, followed by firearms at $408 990, and poisoning at $30 090 per incident.

Table 3. Per incidence lifetime injury costs by mechanism. Adapted from Table 3 from Corso et al. (2000).

Injury Mechanism	Medical Costs	Productivity Losses	Total Costs
Drowning	$13 850	$760 295	$774 145
Firearm	$13 745	$395 245	$408 990
Poisoning	$2593	$27 495	$30 090
Motor Vehicle	$4115	$22 042	$26 157
Burn	$2553	$11 773	$14 325
Falls	$3418	$6866	$10 284
Other	$1751	$6811	$8562
Struck	$1519	$5110	$6629
Cut/Pierce	$1305	$4514	$5819
Total	$2353	$9561	$11 915

The Center for Disease Control (CDC) publishes injury cost data as part of its Web-based Injury Statistics Query and Reporting System (WISQARS, 2019). WISQARS provides injury cost estimates per injury and in total for medical and work-lost costs in two formats: (1) by mechanism (cause) and intent of injury (e.g., unintentional), (2) by nature of injury (diagnosis) and body region affected. Separate estimates are provided for injuries resulting in hospitalization and for those treated by the emergency department. The data can also be parsed by gender and age. For purposes of this report, the WISQARS data presented are for all genders, ages 18 to 65.

WISQARS cost estimates are based on data from the CDC's National Vital Statistics System and the Consumer Product Safety Commission's (CPSC) National Electronic Injury Surveillance System (CPSC 2000). Lawrence et al. (2011) provides details of the estimation methodology.

Table 4 provides a summary of WISQARS-reported average combined cost (medical plus lost work) per nonfatal injury by (1) mechanism and intent and by (2) body region and nature of injury, all genders, ages 18 to 65. For example, the average fall injury results in a cost of $158 790 per hospitalization and $6618 per emergency department visit.

Not shown are the total injury costs by mechanism and intent and by body region and nature of injury, all genders, ages 18 to 65. These are estimated as being between $137 billion to $151 billion for all hospital treated injuries and between $105 billion to $109 billion for all emergency department treated injuries.

Table 4. WISQARS reported average combined cost (medical plus lost work) per nonfatal injury by (1) mechanism and intent and by (2) body region and nature of injury, all genders, ages 18 to 65.

		Average Combined Cost				Average Combined Cost	
Mechanism	**Intent**	**Hospitalization**	**ED Treated**	**Body Region**	**Nature of Injury**	**Hospitalization**	**ED Treated**
Cut/Pierce	Total	$86 309	$3801	Traumatic Brain Injury	Total	$357 574	$9007
Drowning/Submersion	Total	$343 112	$2176	Other Head/Neck	Total	$104 087	$6870
Fall	Total	$158 790	$6618	Torso	Total	$103 124	$7079
Fire/Burn	Total	$68 613	$5586	Upper Extremity	Total	$105 596	$6010
Firearm Gunshot	Total	$109 864	$6783	Lower Extremity	Total	$117 237	$5594
BB/Pellet Gunshot	Total	$129 315	$3781	Other & Unspecified	Total	$124 975	$4935
Foreign Body	Total	$97 959	$2316	Total	Fracture	$136 493	$12 370
Machinery	Total	$165 958	$7390	Total	Dislocation	$122 126	$10 525
Natural Environmental	Total	$108 367	$5234	Total	Sprains/Strains	$94 359	$7056
Bite/Sting	Total	$81 371	$5496	Total	Internal	$308 295	$8989
Overexertion	Total	$114 282	$7422	Total	Open Wound	$86 116	$5079
Poisoning	Total	$18 633	$2550	Total	Amputations	$311 169	$62 496
Struck By/Against	Total	$160 417	$6048	Total	Blood Vessel	$77 362	$7615
Inhalation	Total	$191 824	$3190	Total	Contusion/Superficial	$56 862	$2696
Motor Vehicle Occupant	Total	$194 646	$7547	Total	Crush	$151 106	$8610
Motorcyclist	Total	$206 697	$8274	Total	Burns	$69 189	$6185
Pedal Cyclist	Total	$207 859	$8050	Total	Nerves	$593 581	$10 105
Pedestrian	Total	$218 458	$6551	Total	Other	$91 899	$6259
Other Transport	Total	$165 046	$6801	Total	Total	$155 816	$6441
Other Specified	Total	$26 527	$3170				
Unknown/Unspecified	Total	$168 064	$8003				
Total	Unintentional	$117 306	$6071				
Total	Sexual Assault	$93 035	$8410				
Total	Other Assault	$151 326	$6671				
Total	Self-Harm	$31 510	$4749				
Total	Legal Intervention	$146 627	$6349				
Total	Total	$103 968	$6111				

3.2. Economic Burden of Occupational Injuries and Illnesses: All Professions

Miller and Galbraith (1995) estimated the cost of workplace injuries (occupational disease was not considered) for 1990. Their estimates computed an annual overall cost of $272.4 billion, which includes $33.1 billion for medical services, $116.7 billion in lost productivity, $9.7 billion in insurance costs, and $120.6 billion in lost quality of life (2018 dollars). The overall cost represents about one-fifth to one-half of those found in the Rice et al. and Corso et al. studies above. The average cost per injury was $25 290. Excluding fatal injuries, the total was $187.9 billion annually. Table 5 presents the costs per non-fatal injury by severity, adapted (into 2016 dollars) from Miller and Galbraith (1995). For compensated lost work injuries, quality of life is the largest cost, followed by wage and fringe benefits lost, and then medical and emergency services. For non-compensated lost work and non-lost work injuries, work disruption is the largest cost followed by medical and emergency services.

Table 5. Costs per non-fatal injury by severity, adapted from Miller and Galbraith (1995; Table 4).

Cost Category	Compensated Lost Work	Non-Compensated Lost Work	Non-Lost Work
Medical/EMS	$12 285	$585	$585
Wage/fringe	$29 250	$390	
Household Work	$4875	$195	
Work Disruption	$4875	$1755	$585
Legal & Admin	$4095	$98	$98
Quality of Life	$35 100		
Total	$89 700	$31 200	$1268

Leigh et al. (1997) estimated the economic burden associated with occupational injury, including illness, in the US in 1992. Their estimates are incidence based, meaning the costs represent the lifetime costs associated with the injury or illness, as opposed to the cost in just 1992. (This approach differs from the Miller and Galbraith study.) They estimated that in 1992 there were 6529 fatal injuries, 13.2 million non-fatal injuries, 60.3 thousand fatal illnesses, and 858.2 thousand morbidities. Injuries and morbidities cost $269.6 billion (2018$). The costs include direct and indirect sources. Direct costs included: medical expenses, administrative costs, indemnity administrative costs, property damage, and police and fire services. Lifetime medical costs varied by severity. An injury that resulted in an inability to return to employment was valued at $242.3 thousand, followed by injury that resulted in a return to different employment was valued at $32.8 thousand, injury that resulted in a temporary loss of work was valued at $6 thousand, and no lost work time was valued at $500. The indirect costs included: lost earnings, lost fringe benefits, lost home production, workplace training and restaffing, and time delays. Figure 5 shows the distribution of indirect costs by type. Leigh et al. (1997) found that indirect costs accounted for 66 % of the total cost (this was based on all injuries and illnesses, including fatalities). Of the occupational diseases, the largest losses were found with cancer, circulatory system, and chronic respiratory disease, which were shown to account for 97 % of the costs.

Leigh (2011) estimated total cost of occupational illnesses and injuries for 2007. He estimated the total cost was $305.7 billion (2018 dollars) with 27 % coming from medical costs and 73 % coming from indirect costs (44 % from lost earnings, 12 % from lost fringe benefits, and 17 %

from lost home production). Of the total, Leigh and Marcin (2012) attribute $63.34 billion (2018 dollars) as covered by worker's compensation. The remainder (some 79 %) was shifted to other payers. Figure 6 provides the break-out of cost of injuries and illnesses by payor group. Workers' compensation covered the majority of medical costs, while out-of-pocket expenditures accounted for majority of indirect costs.

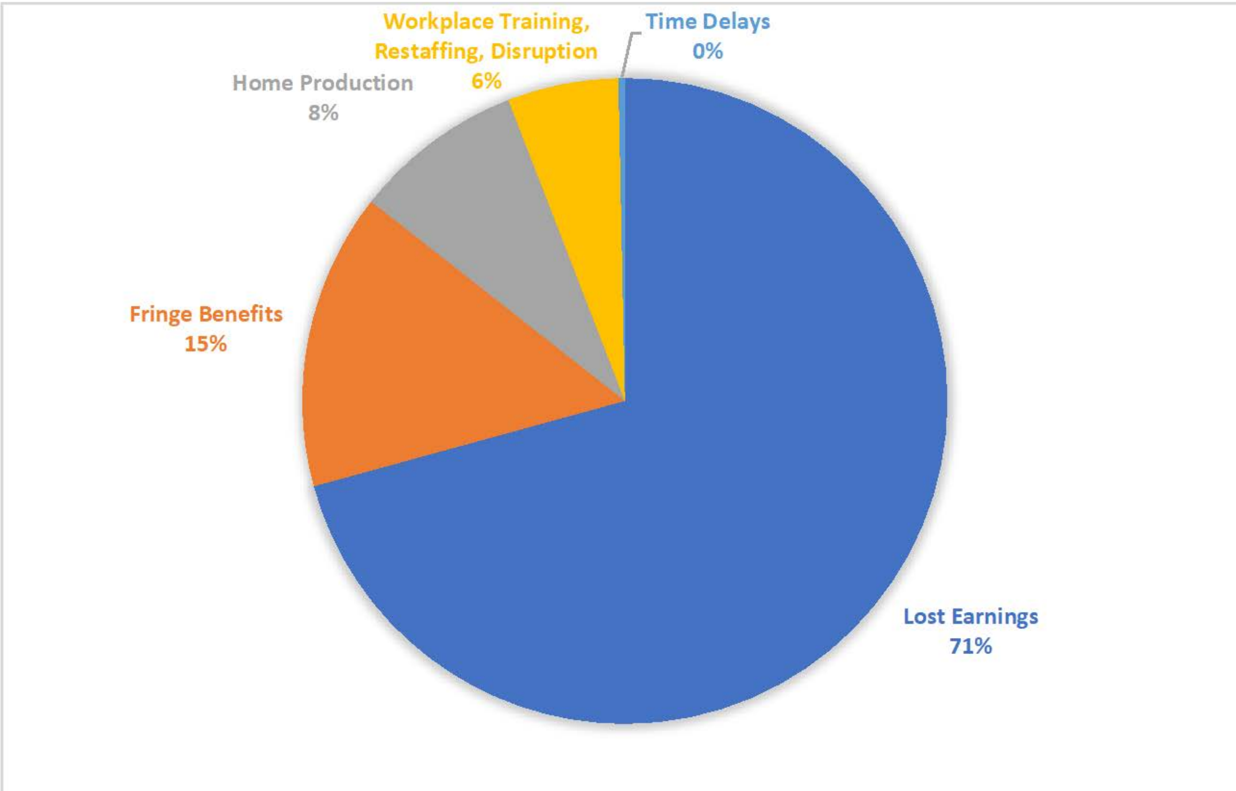

Figure 5. Percent of indirect costs of non-fatal injuries by type, adapted from Table 3 of Leigh et al. (1997).

Mroz et al. (2014) analyzed workers' compensation claims from 1998 to 2008 in Maryland. Median medical and indemnity compensation claims, along with their interquartile range are shown in Figure 7, which was adapted from Mroz et al. (2014) Tables 3 and 4 (2018 dollars shown). Multiple injuries produce the largest median medical claims ($1604), followed by knee ($989) and shoulder ($976) injuries, and occupational disease ($888), respectively. The ordering changes for median indemnity compensation, with occupational disease ($21 217) being the largest, followed by multiple ($13 181), shoulder ($12 591) and knee ($8839) injuries.

Waehrer et al. (2004) compared the costs of occupational injury and illness across states. On a per employee cost basis, average costs demonstrated variation across the United States. Figure 8 shows the per employee costs by state. West Virginia costs averaged $3443 per worker, which was the highest, whereas New Hampshire costs averaged 1131, which was the lowest (2018 dollars). Waehrer et al. found regional differences existed – e.g., southern and western states tended to exhibit higher costs per employee.

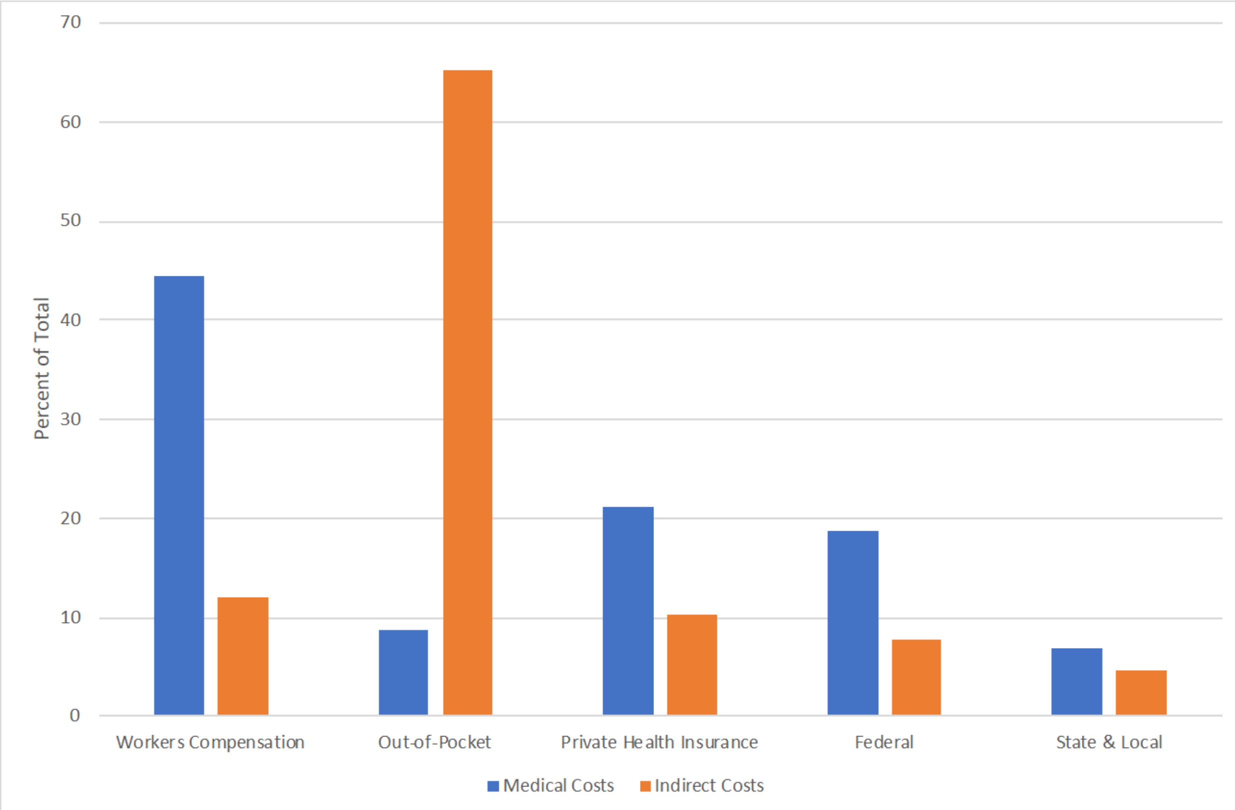

Figure 6. Payers of medical and indirect costs in 2007, adapted from Table 4 of Leigh and Marcin (2012).

Manuele (2011) surveyed several studies to determine the relationship between direct and indirect costs from workplace accidents. His focus was exclusive to those costs borne by employers. He found the ratio of indirect to direct costs commonly was 4:1, but variation in the literature ranged from 1:1 to 30:1. He cautioned that many of the studies were dated (some over 50 years old) and that direct costs have outstripped indirect costs over time.

Asfaw and Souza (2012) compared the incidence and cost of depression between injured and noninjured workers based on 2005 national data. They found 1.04 % of noninjured workers had an outpatient visit, compared to 1.49 % of injured workers. (To be considered an injured worker treated for depression, the injury had to occur within the three months immediately prior the outpatient visit.) The average outpatient expenditure spent on treatment was 63 % higher for injured workers, which amounted to an extra $10.7 million (2018 dollars) spent in 2005. In a study of patient care workers, Williams et al. (2017) found the likelihood of future medical expenditures were higher in workers who had previously experienced a hospital-recorded occupational injury. The odds-ratio of having medical expenditures over three months was 2.17 (1.61 to 2.92 95 % confidence interval [CI]) and over six months was 2.95 (1.96 to 4.45 95 % CI) for previously injured employees. This corresponded to an average expended expenditure increase of $275 ($38 to $549 95 % CI) and $587 ($167 to $1140 95 % CI), respectively.

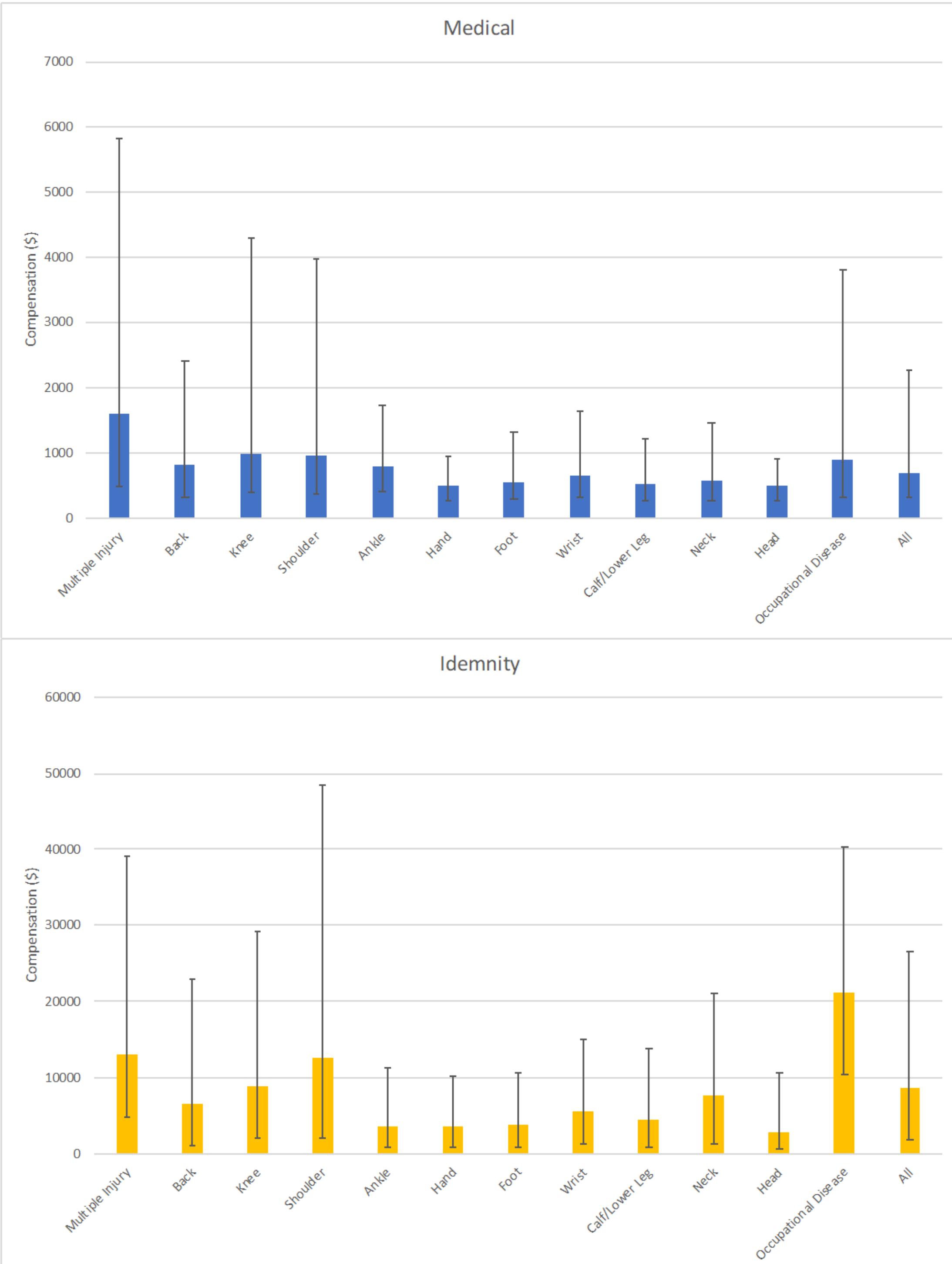

Figure 7. Median medical and indemnity compensation for the top 12 most expensive injury types, by injury types, and their interquartile range, adapted from Tables 3 and 4 from Mroz et al. (2014).

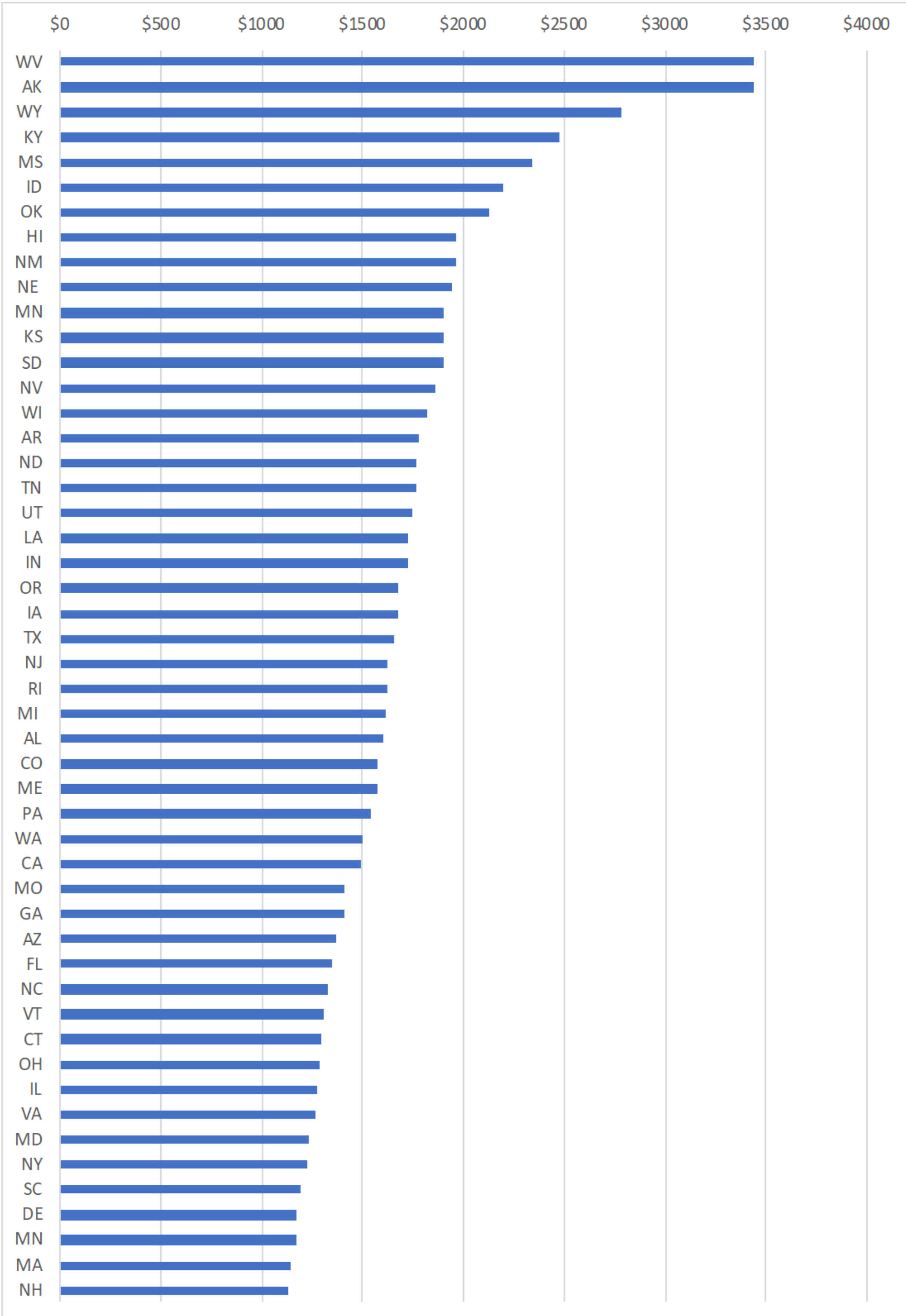

Figure 8. Cost per employee of nonfatal injuries and illnesses, by state, adapted from Table 2 of Waehrer et al. (2004).

Beyond the economic impacts from occupational injuries and illnesses are social consequences. Dembe (2001) develops a conceptual framework describing the complex social context of occupational injuries and illnesses and how the size of the impact can be affected by social forces. The study is descriptive rather than quantitative, but it enumerates several potential social costs, including impacts on family members and coworkers of the injured.

3.3. Economic Burden of Occupational Injuries and Illnesses: Firefighters

Walton et al. (2003) note that little research exists quantifying workers' compensation (medical) costs related to firefighter injuries. Outside of their work, this continues to hold true today. Walton et al. analyzed 1343 workers' compensation claims by firefighters from 1992 to 1999. Figure 9 presents the cost of medical-only and total workers' compensation claims by cause and nature of injury, as adapted from Walton et al (in 2018 dollars). Differences between medical-only and total claims values are due to costs associated with compensation and indemnity (lost work time), legal fees, vocational training, and other expenses. However, it appears differences between medical-only and total costs across cause and nature of injury are relatively the same – i.e., total costs scale with medical costs.

Differences between mean and median costs are due to a skewed distribution of larger costs in the right-hand tail. This provides some insights into the variation in severity of the injuries experienced. For example, focusing on the medical-only workers' compensation for motor vehicle accidents show a mean claim ($9944) roughly five-times the size of the median claim ($1801), which is likely due to the variation in the severity of a motor vehicle injury. Whereas, the mean and median costs from striking against/stepping on caused injuries are roughly the same ($429 vs. $409, respectively), suggesting less variation in the severity of injury experienced.

Focusing on mean total workers' compensation claims, it appears the largest claims are due to causes including motor vehicle ($31 148), followed by overexertion ($15 447) and slips, trips, or falls ($13 773). For nature of injury, the largest mean total claims are for heart disease ($52 885), followed by strains and sprains ($12 769).

A Tridata report, *Economic Consequences of Firefighter Injuries and Their Prevention* (Tridata 2005), estimates the total cost of firefighter injuries to be $4.0 billion to $11.1 billion (adjusted for inflation) based on the range between two sources: CSPC (National Public Services Research Institute 1993) and NHTSA (2002). Another source cited, Meade (1991), fell within the range, while an Australian study (Watson and Ozanne-Smith, 2002) and a NFPA study (Hall 2003) fell outside the range. The Tridata report also provides estimates of individual injury and prevention costs, see Table 6.

Zhuang et al. (2017) estimate the total cost of fire in the U.S., and include a cost estimate of fire-related firefighter injuries, which in 2014 they estimate to be $5.1 billion (2018 dollars). This estimate does not consider long term exposure or occupational disease, nor does it include firefighter injuries that occurred at non-emergencies. Injuries were valued based on the Maximum Abbreviated Injury Scale (MAIS; see U.S. Department of Transportation, 2017), which assigns value based on injury severity. Zhuang et al. adjusted the values downward to 30 % for fireground injuries and 10 % for emergency, non-fireground injuries of the 'moderate' severity MAIS value. The downward adjustment was consistent with Hall (2014), based on evidence that firefighter injury costs tended to be 10 % to 30 % lower than civilian costs, reported in CSPC (2000), based on firefighter location. The adjusted MAIS values ($134 400 per fireground injury; $44 800 per non-fireground injury) were multiplied by the number of firefighter injuries.

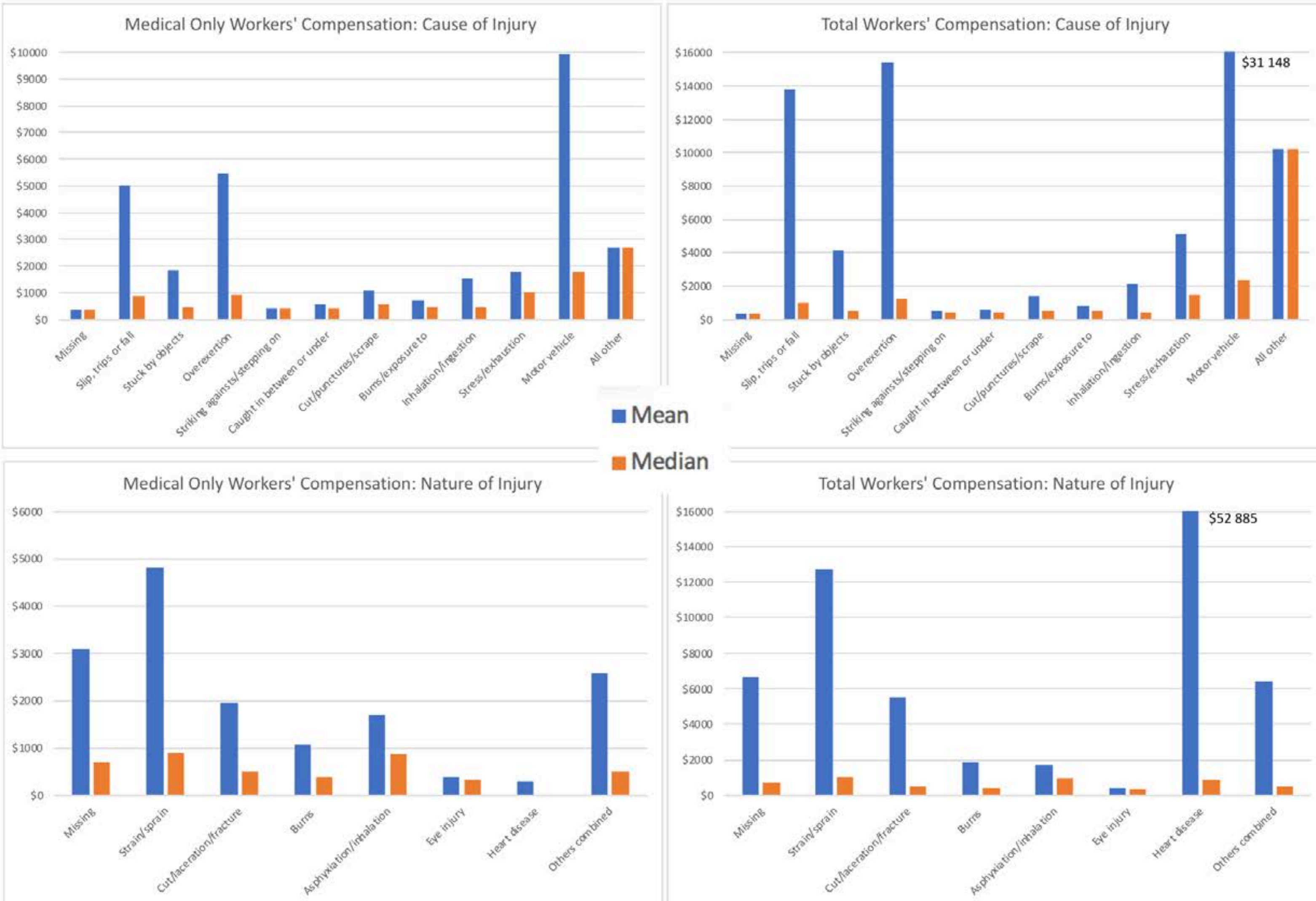

Figure 9. Firefighter workers' compensation costs by cause of injury and by nature of injury, adapted from Table 1 of Walton et al. (2003). Costs shown in 2018 dollars.

Table 6. Firefighter Injury Cost Estimates, adapted from Table 26 of Tridata (2005), adjusted to 2018 dollars.

Type	***Direct Cost***	***Estimate ($ million)***
Workplace	Backfill	
Administration	Legal Fees	286
	Paperwork and Data Collection	10
	Investigations	80
Insurance	Non-Medical Payouts	42
	Medical Payouts	52
Federal Payments	Public Safety Officers Benefit Program	N/A
Lost Income	Volunteer	N/A
	Career	N/A
	Additional Sources	N/A
	Caregiver	N/A
	Physical Changes to Home & Workplace	N/A
	Lost Productivity	N/A
Type	***Indirect Cost***	***Estimate ($ million)***
Insurance	Overhead	21
Prevention	Turn-out gear and other PPE	477 to 572
	Vehicle Safety Measure	N/A
	Personnel Accountability	N/A
	Safety and Survival Training	91 to 206
	Physical Fitness & Wellness Program	107
Community	Deprivation of Volunteerism	N/A
Secondary Economic Effects	Reduced Tax Revenues	N/A
Tertiary Economic Effects	Reduced Spending	N/A
Pain and Suffering		N/A

4. Economic Method for Evaluating Occupational Injury-Related Costs

The literature described in the previous section presents a number of studies seeking to estimate the economic costs from injuries, illnesses, and occupational disease. This section provides an in-depth examination of the general approach used to value such health outcomes. It focuses on the work of Miller and Galbraith (1989) who examined the cost of occupational injuries in the United States. Given the scope of the report only those calculation methods related to non-fatal health outcomes are presented. This section is not meant to imply that only one method is used to estimate occupational injury costs, but rather to provide a deeper understanding of the types of data used and how they are combined to produce national estimates.

Miller and Galbraith (1989) organize occupational injury cost estimates into the following categories:

- Medical and emergency services
- Wage and household work
- Administrative and legal costs
- Workplace disruption

- Quality of life

4.1. Medical & Emergency Services

Medical and emergency services include costs associated with treatment, care, and emergency transport of injured workers. In Miller and Galbraith (1989) medical costs and emergency services are estimated separately as:

$$(Medical\ Costs)_i = \frac{(Value\ of\ Workers'Comp\ Medical\ Claims)_i}{(\%\ of\ Workers\ Covered)_i}$$

where *i* indexes injury type. Injury types include: permanently disabling, others that qualify for disability compensation, and injuries with only medical care. (Note: the value of workers' compensation claims are divided by the percent of workers covered to arrive at an estimate of the total medical cost that include for workers not included in workers' compensation. This technique is used elsewhere.)

Emergency services (transportation costs) are estimated as:

$$Emergency\ Services = (Transport\ Costs)\ x\ (No.Injured\ at\ Work)\ x\ (Multiplier)$$

A multiplier is used to scale up to include for associated police and fire costs.

4.2. Wage & Household Work

Wage and household work includes lost wages, fringe benefits, and ability to provide household services. They are computed as follows.

Lost wages are computed in three steps (workers' compensation disability lost wages, other disability payouts, and the value of sick leave lost):

$$Workers'Comp\ Disability\ Payments = \frac{(Workers'Comp\ Survivor\ Benefits\ and\ Disability\ Payments)\ x\ (\%\ of\ Claims\ for\ Injuries)}{\%\ of\ Wage\ Loss\ Covered\ by\ Workers'Comp}$$

$$Other\ Disability\ Payouts = (Disability\ Payments\ Per\ Person\ for\ Permanently\ Disabled\ from\ Highway\ Crashes)\ x\ (No.of\ Permanent\ Disabled\ Injuries)$$

$$Value\ of\ Sick\ Leave\ Lost = (\#\ Lost\ Work\ Injuries)x\ (\$\ Per\ injury\ Reimbursement\ of\ Sick\ Leave)\ x\ (\%\ of\ Injured\ Workers\ Reimbursed\ by\ Sick\ Leave)$$

Fringe benefits are calculated as:

$$Fringe\ Benefits\ Lost = 20\ \%\ of\ Wages$$

Lost household work is valued as:

$$Household\ Work\ Days\ Lost = (Multiplier)\ x\ (Work\ Days\ Lost)\ x\ \%\ of\ Daily\ Wage$$

where the multiplier used is equal to the number of days per year (365) divided by the number of work days per year (243). In Miller and Galbraith, lost household production is assumed to be equal to 21.4 % of the daily wage (see Miller and Galbraith for details).

4.3. Legal & Administrative Costs

Legal and administrative costs account for the management and overhead costs associated with the various insurances. These are computed as:

$$(Legal\ \&\ Admin\ Costs)_i = (\ Insurance\ Payments)_i\ x\ (\%\ of\ Payment\ for\ Administrative\ Cost\ Overhead\ )_i$$

where *i* indexes insurance type. Types of insurance include: health, life and disability, Workers' compensation, auto liability, auto property damage, and sick leave.

4.4. Workplace Disruption

Workplace disruption accounts for costs related to lost productivity and time due to restaffing and training. The costs are divided between supervisory and non-supervisory time lost. The assumptions used are:

- Supervisor time = ¼ time lost from injuries
- Compensated lost work injury = 1 month of productivity (other employees)
- Non-compensated lost work injury = 2 days of supervisory time + 4 days non-supervisory time
- Crash injury = 2 days of supervisory time + 1 day non-supervisory time
- No work lost injury = 1 day of supervisory time + 1 day non-supervisory time

4.5. Quality of Life

Quality of life accounts for the reduced ability and pain and suffering. The calculation is based on the willingness to pay for the reduction in occupational injury risk. Miller and Galbraith (1989) computed it as:

$$Quality\ of\ Life = (Cost\ of\ Quality\ of\ Life\ of\ Fatality\ x\ No.\ of\ Fatalities)\ x$$

$$\left(\frac{1}{\%\ of\ Workplace\ Risk\ Compensation\ that\ is\ deemed\ Fatality\ Risk} - 1\right)$$

5. Matching Firefighter Injuries, Illnesses, Health Exposures, and Occupational Disease to Economic Costs Per Incident

The firefighter health outcome data from Section 1 was combined ('matched') to the economic health outcome cost data from Section 3 to produce national estimates of non-fatal firefighter health outcome costs. Table 7 presents the matching protocol developed. The health outcome extent of each economic data source were matched to data elements found in the NFPA, NFIRS, and SOII data. For example, Corso et al. (2006) provide injury cost data by 'mechanism of injury' (e.g., "falls, jump, slip") that was matched to NFPA's 'nature of injury' (e.g., "falls"). In some cases, the matching occurred over two variables (e.g., WISQARS 'injury by body part by type' with NFIRS 'primary apparent symptom' and 'primary body part'). In other cases matching could be performed only on the total number of injuries—e.g., Miller and Galbraith (1995) provide costs by cost category (e.g., medical costs) rather than by a factor related to the injury (e.g., cause). In such cases the total number of injuries provided by NFPA, NFIRS, and SOII were multiplied by the individual cost categories and summed for a total injury cost. In other instances (e.g., TriData [2004]), only the average cost per injury could be calculated. These multiplied by the total number of injuries provided by NFPA, NFIRS, and SOII were used to compute a total injury cost.

The total economic costs, based on matching the injury cost literature (economic source data) with each of the national firefighter statistics data, are shown in Table 8. Table 8 also provides lists of direct and indirect costs considered in the economic source data.

The total cost estimates shown in Table 8 demonstrate considerable variation across the economic source data used and also across the firefighter injury statistical data used. The estimates based on Rice et al. are much lower than the rest. This is due to the inability to match those injury cause-types found in the NFPA, NFIRS, and SOII data because Rice et al. is focused primarily on diseases. Only those injuries related to cardiac and stroke could be matched.

A number of matches produce estimates (or ranges that fell within) of $100 million or less. This includes WISQARS, Watson and Ozanne-Smith, and TriData. The lower range of the WISQARS estimates occurs if assuming all injuries resulted in emergency department treatment (non-hospitalization). Obviously this is a poor assumption; however, the statistical data do not provide such a distinction. The estimates based on the Watson and Ozanne-Smith approach also yield the smallest estimates in the TriData's summary comparison. Their average cost of an injury works out to only $5198. Two other TriData-based approaches yielded estimates under $100 million. One was based on the average injury cost category estimates shown in Table 6. The average cost for these ranged between $1469 to $1734 per injury. The other TriData-based approach was used to produce a range based on injury severity, tied to the MAIS scale. Because the NFIRS data does not neatly map injuries to this scale, a range was produced. The lower end of the range produces small estimates, but assumes, unrealistically, that all injuries are minor.

Another grouping of estimates yielded totals that exceed $100 million, but generally were less than $1 billion. These include: Corso et al., Leigh (1997, 2011), Mroz et al., Walton et al., Meade, and NPSRI. The Leigh-based and NPSRI-based mid-range estimates apply to the NFIRS, SOII NFPA lost time matched injuries. These sources are based on a smaller number of injuries than the total number of injuries reported by NFPA. Mroz et al. and Walton et al. only considers workers' compensation claims. Meade cost estimates are based on individuals willingness-to-pay to avoid a fire injury, and not on cost data.

Miller and Galbraith, Leigh (1997, 2011), WISQARS, NHTSA, NPSRI, Zhuang et al., and Hall-based estimates all yielded total estimates in the billions of dollars. This is particularly true when matching those with the NFPA injury statistics, as it accounts for more injuries than the other data sources. (The upper bound from the MAIS-based estimates are excluded because it requires the unrealistic assumption that all injuries were of maximum severity.) Focusing on the NFPA-based estimates, these sources ranged from $1.2 billion to $18 billion. Dropping the highest and lowest estimates produces a range of $1.6 billion to $8.4 billion. Excluding those based on TriData, the range becomes $1.6 billion to $5.9 billion. These estimates track well against the TriData estimates of $2.8 billion to $7.8 billion (inflation adjusted). However, an advantage of the current approach is the ability to track injury costs by cause and nature. Given the range of $1.6 billion to $5.9 billion is consistent with previous literature and is based on fewer data limitations that the other (lower) estimates, this is the most defensible estimate.

Table 9 provides a comparison of the average injury costs and their variation across estimates produced when matching with the NFPA, NFIRS, and SOII data. Differences occur due to the matching process—see Table 7 to review the field matching process. For all but two approaches, the range maximum is no more than 47 % larger than the range minimum. For two approaches with the largest variation, in both cases assumptions on the severity of the injury were required (e.g., produce a range assuming all injuries were the minimum severity and then assuming all injuries were the maximum severity).

Table 10 presents the total annual costs normalized (divided by) the numbers of fire departments, firefighter injuries, firefighters, and total calls to provide additional perspective of the magnitude. Based on the high estimate ($5.9 billion), firefighter injuries result in a loss equivalent to $197 860 per fire department per year, $5412 per firefighter per year, or $170 per call per year. The average lost per injury is $95 031.

Table 7. Process to match national firefighter injury statistical data to economic source data (by extent of injury).[a,b]

Source	Extent	NFPA	NFIRS	SOII
Rice et al. (1985)	Illness by Diagnosis	Match on *Nature of Injury*	Match on *Primary Apparent Symptom*	Match on *Musculoskeletal Disorders*
Corso et al. (2006)	Mechanism of Injury	Match on *Cause of Injury*	Match on *Cause of Firefighter Injury*	Match on *Event or Exposure*
WISQARS (2019)	Injury by Cause by Intent	Match on *Cause of Injury* (n/a Intent)	Match on *Cause of Firefighter Injury* (n/a Intent)	Match on *Event or Exposure*; Match on *Nature of Injury, Illness*
	Injury by Body Part by Type	Match on *Nature of Injury* (n/a body part)	Match on *Primary Apparent Symptom* & *Primary Body Part*	Match on *Nature of Injury, Illness*; Match on *Part of Body Affected*
Miller & Galbraith (1995)	Injury by Cost Category	Multiply Total Injuries by Cost Categories	Multiply Total Injuries by Cost Categories	Multiply Total Injuries by Cost Categories
Leigh et al. (1997)	Injury by Cost Category	Multiply Total Injuries by Cost Categories	Multiply Total Injuries by Cost Categories	Multiply Total Injuries by Cost Categories
Leigh (2011)	Injury by Severity; Injury by Cost Category	Match on *Lost Time Injuries*; Multiply Total Injuries by Cost Categories	Match on *Severity*; Multiply Total Injuries by Cost Categories	Match on *Lost Time Injuries*; Multiply Total Injuries by Cost Categories
	Illness by Disease	n/a	n/a	Match on *Musculoskeletal Disorders*
Mroz et al. (2014)	Injury by Part of Body	n/a	Match on *Primary Body Part Injured*	Match on *Part of Body Affected*
Walton et al. (2003)	Injury by Cause	Match on *Cause of Injury*	Match on *Cause of Firefighter Injury*	Match on *Event or Exposure*
	Injury by Type	Match on *Nature of Injury*	Match on *Primary Apparent Symptom*	Match on *Nature of Injury, Illness*
TriData (2004)	Injury	Multiply Total Injuries by Average Cost	Multiply Total Injuries by Average Cost	Multiply Total Injuries by Average Cost
	Injury by Severity	Match on *Lost Time Injuries*	Match on *Severity*	Match on *Lost Time Injuries*
Zhuang et al. (2017)	Injury	Match on *Type of Duty*	Match on *Activity at Time of Injury*	n/a

[a] Some sources contain extent of injuries that can be matched to multiple fields within the national firefighter statistics data. These fields are separated by a semicolon. In a few instances multiple matching (matching on two sets of fields) were performed. These are identified by an ampersand.

[b] Some sources did not provide cost data by extent of injury. In these instances the total cost of injuries provided by the source were multiplied by the total number of injuries in the national firefighter statistics data.

Table 8. Total economic costs of firefighter injuries based on matching with economic source data.

Source	Population	Direct Costs	Indirect Costs	Total Costs by Injury Source Data NFPA Million	NFIRS Million	SOII Million
Rice et al. (1985)	General	• Medical	• Lost wages	$1.2	<$0.1	$12.7
Corso et al. (2006)	General	• Medical	• Lost wages • Lost fringe benefits (temporary, long-term, permanent)	$285.3	$140.0	$112.5
WISQARS (2019)	General	• Medical (treatment and rehabilitation)	• Lost wages • Lost fringe benefits • Lost home production	$125.6 to $5895.0	$70.3 to $1393.5	$75.4 to $1508.2
Miller & Galbraith (1995)	Occupational	• Medical • Emergency services	• Lost wages • Lost home production • Legal and administrative, • Recruitment, retraining • Lost special skills • Quality of life	$5883.8	$809.4	$1161.9
Leigh et al. (1997)	Occupational	• Medical • Insurance administrative	• Lost wages • Lost fringe benefits • Lost home production • Recruitment, retraining • Lost coworker productivity • Time delays	$1190.3	$163.8	$235.1
Leigh (2011)	Occupational	• Medical • Insurance administrative	• Lost wages • Lost fringe benefits • Lost home production • Recruitment, retraining • Lost coworker productivity • Time delays	$380.9 to $1644.6	$92.2 to $226.2	$245.1 to $324.8
Mroz et al. (2014)	Occupational	• Workers' compensation (wage replacement, medical, vocational rehabilitation)			$131.3	$138.1
Walton et al. (2003)	Firefighter	• Workers' compensation (wage replacement, medical, vocational rehabilitation)		$231.6	$152.3	$128.1 to $147.8
TriData (2004): Watson & Ozanne-Smith (2002)	General	• Medical and disability	• Lifetime hospitalization and non-hospitalization	$322.7	$44.4	$63.7

Table 8. Total economic costs of firefighter injuries based on matching with economic source data. (*Continued*)

Source	Population	Direct Costs	Indirect Costs	Total Costs by Injury Source Data NFPA Million	NFIRS Million	SOII Million
TriData (2004): Watson & Ozanne-Smith (2002)	General	• Medical and disability	• Lifetime hospitalization and non-hospitalization	$322.7	$44.4	$63.7
TriData (2004): NHTSA (2002)	Motor vehicle crash	• Medical • Emergency services	• Lost home production, • Market productivity • Insurance and legal administration • Workplace • Property damage	$6454.4 to $8390.7	$887.9 to $1154.3	$1274.6 to $1656.9
TriData (2004): Meade (1991)	Fire-related	• Willing-to-pay to avoid injuries from fire		$4948.4	$680.7	$977.2
TriData (2004): NPSRI (1992)	Burn and anoxia	• Medical, inc hospitalization • Emergency services	• Lost wages • Psychological • Quality of life • Pain and suffering • Litigation	$3012.0	$414.4	$594.8
TriData (2004): Hall (2003)	Firefighter	• Medical	• Liability claims, including pain and suffering	$17964.7	$2471.4	$3547.5
TriData (2004) Cost Components	Firefighter		• Insurance administrative and legal • Prevention (e.g., PPE) • Training • Fitness programs	$91.2 to $107.7	$12.5 to $14.8	$18.0 to $21.3
TriData (2004) MAIS	Firefighter			$4.6 to $29354.5	$513.9	$1802.3
Zhuang et al. (2017)	Firefighter	• Medical	• Liability claims, including pain and suffering	$3841.8	$1159.1	

Table 9. Comparison of average per injury economic costs of firefighter injuries.[c]

Source	Extent	NFPA	NFIRS	SOII	% Range
Rice et al. (1985)	Illness by diagnosis	$2164	$1950	$2164	11%
Corso et al. (2006)	Mechanism of Injury	$11 669	$8548	$9169	37%
WISQARS (2019)	Injury by cause	$95 285	$82 875	$116 031	40%
	Injury by cause	$5136	$4386	$6446	47%
	Injury by intent			$87 556	
	Injury by intent			$6225	
	Injury by type	$94 950			
	Injury by type	$9123			
	Injury by body part by type		$94 050	$122 815	31%
	Injury by body part by type		$5505	$6142	12%
Miller & Galbraith (1995)	Injury by cost category	$94 770	$94 770	$94 770	
Leigh et al. (1997)	Injury by cost category	$19 172	$19 172	$19 172	
Leigh (2011)	Injury by severity	$19 995	$7388	$19 995	171%
	Injury by cost category	$26 490	$26 490	$26 490	
Mroz et al. (2014)			$8487	$11 244	32%
Walton et al. (2003)	Injury by cause	$9473	$9507	$12 048	27%
	Injury by type	$9563	$8230	$10 517	28%
TriData (2004): Watson & Ozanne-Smith (2002)	Injury	$5198	$5198	$5198	
TriData (2004): NHTSA (2002)	Injury	$103 960 To $135 149	$103 960 To $135 149	$103 960 To $135 149	
TriData (2004): Meade (1991)	Injury	$79 703	$79 703	$79 703	
TriData (2004): NPSRI (1992)	Injury	$48 515	$48 515	$48 515	
TriData (2004): Hall (2003)	Injury	$289 356	$289 356	$289 356	
TriData (2004)	Injury	$83 136	$83 136	$83 136	
	Injury by severity	$88 689	$60 163	$147 003	144%
Zhuang et al. (2017)	Injury	$103 539	$134 400		30%

[c] '% Range' is computed as the absolute percent difference between the minimum and maximum, relative to the minimum. No value is provided in cases where a direct comparison could not be made or when the per injury cost estimate is constant.

Table 10. Total annual cost of firefighter injuries normalized on a per-unit basis.

		Total Firefighter Injury Cost Per Unit	
Unit	Number	Low Estimate ($1.6 Billion)	High Estimate ($5.9 Billion)
Fire Departments[a]	29 819	$53 657	$197 860
Firefighter Injuries[b]	62 085	$25 771	$95 031
Firefighters[a]	1 090 100	$1468	$5412
Total Calls[c]	34 683 500	$46	$170

Sources: [a] Evarts and Stein (2019), [b] Haynes and Molis (2017), [c] NFPA (2019)

6. Data Gaps

The national data sources, described above, account for injuries, illnesses, and health exposures that typically occur during line-of-duty (on-duty) activities, transport, or as part of training. However, they do not capture longer-term health effects from occupational diseases, such as cancer. Tracking the national prevalence of occupational diseases from long-term exposures of firefighters to toxic environments does not occur (Fahy, et al. 2017). However, the IAFF's Fire Department Death and Injury Surveys do identify the leading causes of firefighter deaths from occupational diseases. Statistics of firefighter deaths due to occupational diseases can provide some insights into their lethality, but they may provide only limited information related to their prevalence in active and retired firefighters. For example, if the relative lethality of occupational diseases is equal across causes, and exposure rates are constant over time, fatalities from occupational disease would provide insights into prevalence in active and retired firefighters. However, it is unlikely these conditions exist.

The IAFF reports cancer (48.3 %) was the leading cause of death from occupational disease based on a summary of their Death and Injury Surveys from 1981 to 2000.[9] Heart disease and infectious disease were reported as being responsible for 41.7 % and 10 % of deaths from occupational diseases, respectively. In the same report it was shown that of those firefighters who retired early due to occupational diseases, heart disease (53.4 %), lung disease (17.2 %), cancer (9.7 %), mental stress (7.6 %), hearing loss (5.8 %), and other diseases (6.2 %) were main the causes.

Much of the available literature on mortality and incidence is based on cohort studies, usually specific to a region or city, much of which is not necessarily representative nationwide (or even for the US). Also, the literature tends to focus on occupational disease, which tends to exclude volunteers.

The literature detailed below summarizes the results from several studies that estimated the mortality or incidence risk (or both) associated with firefighting. The studies listed are not meant to comprise an all-inclusive review of the literature, but rather, they are included to provide a general overview of current findings. Where possible, studies providing meta-analysis are included. These synthesize the findings of several studies into a single set of conclusions, which provide some robustness to the findings. In addition to meta-analyses, other highly-cited papers with notable conclusions are included. It should be noted that the studies presented often vary based on year and population of study. Differences across studies could be due to regional or temporal difference, as well as methodological difference.

The literature is categorized into the topics of cancer, mental health, and other occupational diseases (focused primarily on heart disease). Each topic begins with a brief overview of the mortality or incidence found in the general US adult population to provide some contrast with the literature focused on firefighters. The last subsection focuses on lost fire department (crew) productivity due to lost work time health outcomes.

6.1. Cancer

In 2018, the National Cancer Institute estimated that over 1.7 million new cases of cancer will be diagnosed in the U.S. (439.2 per 100 000 adults) and over 600 thousand people will die from

[9] IAFF Death & Injury Summary 1981-2000 report obtain from Lori Moore-Merrell (05 April 2018).

cancer (163.5 per 100 000 adults).[10] The most common cancers, based on new cases, are breast cancer, lung and bronchus cancer, prostate cancer, colon and rectum cancer, melanoma of the skin, bladder cancer, non-Hodgkin lymphoma, kidney and renal pelvis cancer, endometrial cancer, leukemia, pancreatic cancer, thyroid cancer, and liver cancer, in descending order.[11] The Center for Disease Control reports that 3 % to 6 % of all cancers worldwide were due to occupational exposures (Driscoll et al. 2005; Rushton et al. 2012).[12]

LeMasters et al. (2006) documents a meta-analysis of 32 studies that quantified cancer risk for firefighters. Their analysis included studies from the U.S. and abroad, and most were focused on estimating mortality (as opposed to incidence). The authors also updated an early meta-analysis performed by Howe and Burch (1990). Through their meta-analysis approach, LeMasters et al. (2006) classified cancer sites (e.g., multiple myeloma, prostate, brain) by likelihood of cancer risk (probable, possible, unlikely) and an associated summary risk estimate. Figure 10 provides the summary risk estimates and likelihood of cancer, by cancer site, based on Table 2 in LeMasters et al. (2006). They found firefighters had a 'probable' likelihood of multiple myeloma, non-Hodgkin lymphoma, and prostate cancers, with estimated summary risks as 1.53 (1.21 to 1.94 95 % CI), 1.52 (1.31 to 1.73 95 % CI), and 1.28 (1.15 to 1.43 95 % CI), respectively. (An estimated summary risks of 1.0 would imply no statistical association.) Nine other cancer sites (e.g., testis, skin) were determined to have a 'possible' likelihood of cancer for firefighters.

Gender Differences

Ma et al. (2006) linked data between the Florida Fire Marshal and the Florida Cancer Data System to examine cancer incidence in professional firefighters from 1981 to 1999. Of the 36 813 firefighters sampled, 1022 reported cancer (2.7 %). A focus of the study was to measure gender differences in cancer rates. Ma et al. found male firefighters had an overall statistically significant lower cancer incidence than the general population (age adjusted), while female firefighters had an overall statistically significant higher cancer incidence rate. Male firefighters were also shown to have lower brain, oral cavity, lung, stomach, and cancer of the lymphopoietic system than the general population. However, male firefighters exhibited elevated rates, compared to the general population, for bladder, testicular, and thyroid cancers, with standardized incidence ratios (SIR) of 1.29 (1.01 to 1.62 95 % CI), 1.60 (1.20 to 2.09 95 % CI), and 1.77 (1.08 to 2.73 95 % CI), respectively. (An estimated SIR of 1.0 would imply no statistical association.) There were no instances where female firefighters were shown to have had a lower incidence rate than the general population. Female firefighters demonstrated higher risks for cervical cancer, Hodgkin disease, and thyroid cancer, with SIRs of 5.24 (2.93 to 8.65 95 % CI), 6.25 (1.26 to 18.30 95 % CI), and 3.97 (1.45 to 8.65 95 % CI), respectively. The results suggest that firefighters are at risk for particular types of cancers, compared to the general public, and while there are some commonalities between genders of firefighters, there are some differences too.

[10] Per https://www.cancer.gov/about-cancer/understanding/statistics
[11] Ibid.
[12] https://blogs.cdc.gov/niosh-science-blog/2014/02/04/world-cancer-day/

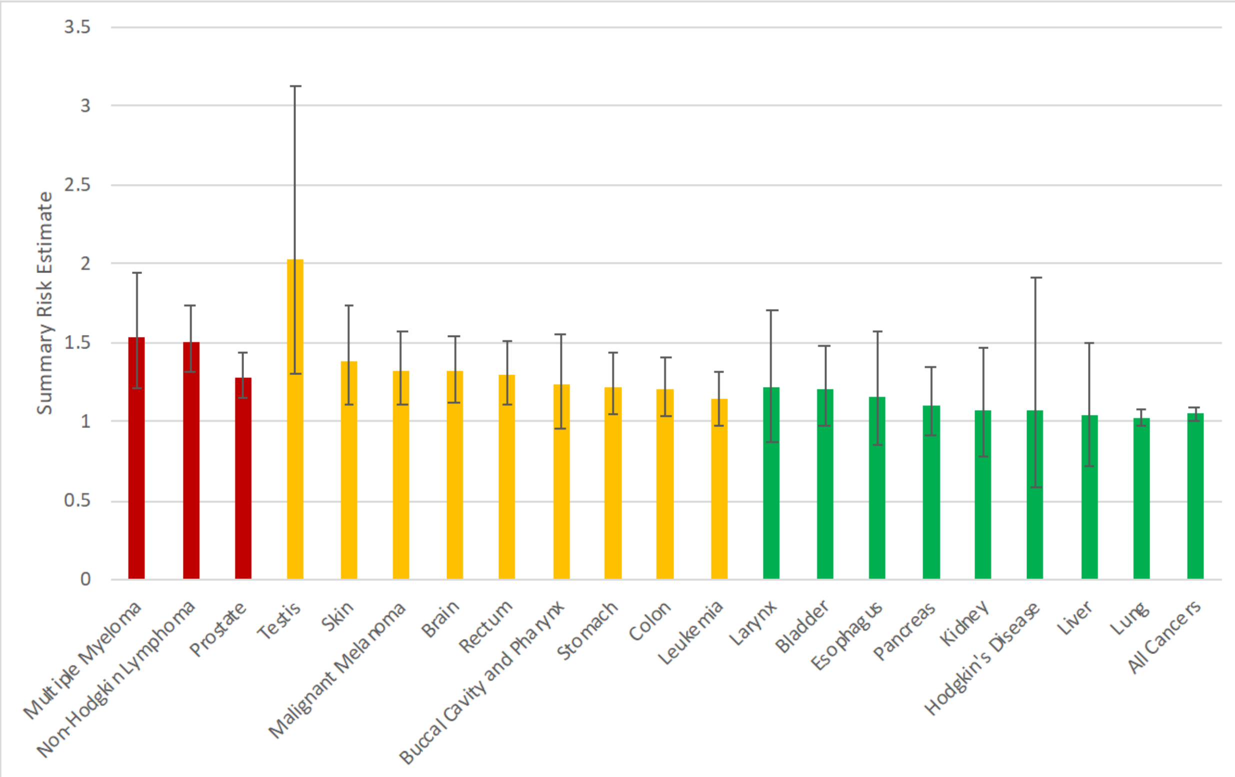

Figure 10. Summary risk estimates (along with 95 % confidence intervals) and likelihood of cancer (probable in red, possible in orange, unlikely in green) by cancer site for firefighters adapted from LeMasters et al. (2006), Table 2. (Confidence interval ranges that do not include 1 are statistically significant and indicate elevated cancer risk in firefighters.)

Employment Duration

Youakim (2006) estimated standardized mortality rates (SMR) and standardized incidence rates (SIR), by duration of employment, for six cancer types, using a meta-analysis of 26 studies from 1966 to 2005. He found several statistically significant SMRs by duration of employment (see Table 11). None of the incidence rates (SIR) were found to be statistically significant (95 %), however (not shown). Because increased mortality risk was found with duration of employment, but not with the incidence analysis, Youakim (2006) theorizes that firefighting may not increase the risk of developing new cancers, but rather, may increase the likelihood of malignancy of pre-existing cancers. A somewhat different interpretation, not provided by Youakim, is firefighting employment duration may increase the likelihood of malignancy of cancer, thereby decreasing the ability to treat, irrespective of the time of its occurrence.

Table 11. Standardized mortality rates by duration of firefighter employment (Youakim, 2006).

Duration of Employment	Cancer	Standardized Mortality Rates	95 % Confidence Interval
Under 10 years	Colon	1.64	1.04 to 2.45
10 or more years	Kidney	2.86	1.67 to 4.58
20 or more years	Kidney	2.80	1.60 to 4.55
30 or more years	Brain	2.53	1.27 to 7.07
	Colon	1.51	1.05 to 2.11 9
	Kidney	6.25	1.70 to 16.00
	Leukemia	2.87	1.43 to 5.14
40 or more years	Colon	4.71	2.03 to 9.27
	Bladder	5.71	1.56 to 14.63

Incidence and Mortality Rates Differences

Bates (2007) investigated the incidence of cancer in firefighters using the California Cancer Registry, from 1988 to 2003. The sample included 3659 cancer registrations for those who identified their main occupation as ‘firefighter’ (including retirees). Bates (2007) reported testicular cancer, melanoma, brain cancer, esophageal cancer, and prostate cancer were found in higher rates for firefighters, with odds ratios of 1.54 (1.18 to 2.02 95 % CI), 1.50 (1.33 to 1.70 95 % CI), 1.35 (1.06 to 1.72 95 % CI), 1.48 (1.14 to 1.91 95 % CI), and 1.22 (1.12 to 1.33 95 % CI), respectively. He suggested the reason incidence and mortality risk rates may differ is due to the low fatality rates of some cancers.

Comparisons with Police

Kang et al. (2008) evaluated the cancer risk of white, male firefighters in Massachusetts from 1987 to 2003, and compared their rates with police and other professions based on the Massachusetts Cancer Registry. Figure 11 graphs the standardized morbidity odds ratios, and their 95 % confidence intervals, provided in Tables II and III from Kang et al. (2008). (A standardized morbidity odds ratio of 1.0 implies no statistical association.) In their analysis, Kang et al. did not use non-disease controls as the unexposed group. Rather, they used police and all other occupations from the cancer registry as the unexposed group, relative to firefighters (and vice-versa). Thus, their comparison does not provide information regarding the overall riskiness of specific professions, because only groups with cancer were included in the analysis, but rather their comparison was meant to highlight differences in the type of cancers of those with cancer across professions. However, their results show few differences across occupations, except for skin melanoma. While Kang et al. (2008) does not evaluate differences in cancer incidence rates, they find that malignancy of cancer (once diagnosed) are not statistically difference across occupation types examined, including firefighters. These results differ from the findings presented in Youakim (2006). These studies differ in terms of population and time periods studied.

In a meta-analysis of 31 studies, Sritharan et al. (2017) evaluated the incidence and mortality risk of prostate cancer for firefighters and police officers. The analysis was based on studies published between 1980 and 2017.[13] The calculated meta-risk estimates (mRE) demonstrated that firefighter (1.17; 1.08 to 1.28 95 % CI) and police officers (1.12; 1.02 to 1.28 95 % CI) exhibited elevated prostate incidence risk and of a similar magnitude. Sritharan et al. discussed risk factors, such as occupational stress, shift work, and chemical exposure, as possible contributors to the elevated prostate cancer incidence rate. Neither profession was shown to be associated with excess mortality risk, however. The authors cautioned that the heterogeneity between studies were considerable, affecting the precision of their estimates.

World Trade Center

Zeig-Owens et al. (2011) estimated the standardized incidence ratio (SIR) of cancer for firefighters (n = 9865) who responded to the World Trade Center (WTC) 9/11 attacks. They evaluated the SIRs for all cancers (combined) and for site-specific locations (e.g., stomach) in the first seven years after 9/11. Zeig-Owens et al. (2011) found no statistical significance of increased overall cancer SIR of 1.10 (0.98 to 1.25 95 % CI) when exposed firefighters were compared to the general male population in the US with similar demographic composition. The SIR is 1.19 (0.96 to 1.47 95 % CI) when compared to non-exposed firefighters (and correcting for possible surveillance bias due to increased access to health screenings). Without correcting for surveillance bias increased the SIR to 1.32 (1.07 to 1.62 95 % CI). The authors suggest, however, that firefighters have a different background cancer risk profile than the general population—e.g., they note that FDNY firefighters have a lower smoking rate. None of the site-specific cancer SIRs were significant. They also caution that seven years is a short post-exposure analysis period and follow-up is recommended.

Fire Exposure

Daniels et al. (2014) analyzed the cancer risk of 29 993 career firefighters employed sometime between 1950 and 2009 in Chicago, Philadelphia, or San Francisco. Standardized mortality ratios and standardized incidence ratios were estimated based on death certificates and state cancer registries, respectively. Table 6 graphs the standardized morbidity odds ratios and standardized incidence ratios, along with their 95 % confidence intervals, by cancer types for firefighters, as reported in Daniels et al. (2014). Figure 12 shows that the mortality and incidence risk (all cancers and first cancer) from all cancers, esophagus, intestine, large intestine, lung, kidney, mesothelioma, and buccal and pharynx cancers were found significantly elevated for firefighters. Increased mortality risk, but not incidence risk, was found for rectal cancer only. Increased incidence risk, but not mortality risk was found for bladder (first cancer) and other cancer (all cancer). The authors note a generally consistency between their results and those as reported by LeMasters et al. (2006), with the exception being the lack of significance with cancers of the testes, brain, and lymphohematopoietic systems.

[13] Sritharan et al. (2017) meta-analysis included several of the previously cited references in this report—Daniels et al. (2014), Mae et al. (2006), and Kang et al. (2008).

Using a subset of the firefighters included in Daniels et al. (2014), Daniels et al. (2015) examined 19 309 male firefighters and correlated fire exposure with cancer deaths and incidences. They found significant positive correlations between fire-hours (total time spent at fires) and lung cancer mortality (hazard rate ratio: 1.39; 1.12 to 1.73 95 % CI), and between fire-runs (any response to a call requiring the deployment of apparatus) and leukemia mortality (hazard rate ratio: 1.45; 1.00 to 2.35 95 % CI). A few significant negative correlations were found with exposures (e.g., prostate cancer), which the authors attributed to possible increased medical screenings for firefighters (compared to the general population). No statistical correlations were found with exposure-days (days with a possibility of exposure).

Overall, the literature presented provides statistical evidence of elevated cancer risks for firefighters and other first responders due to their profession. While there is general agreement across studies, the strength of the statistical association and the estimated magnitude of incidence and mortality rates vary, and vary across cancer types. Again, it should be noted that the studies presented often vary based on year and population of study. Differences across studies could be due to regional or temporal difference, as well as methodological difference.

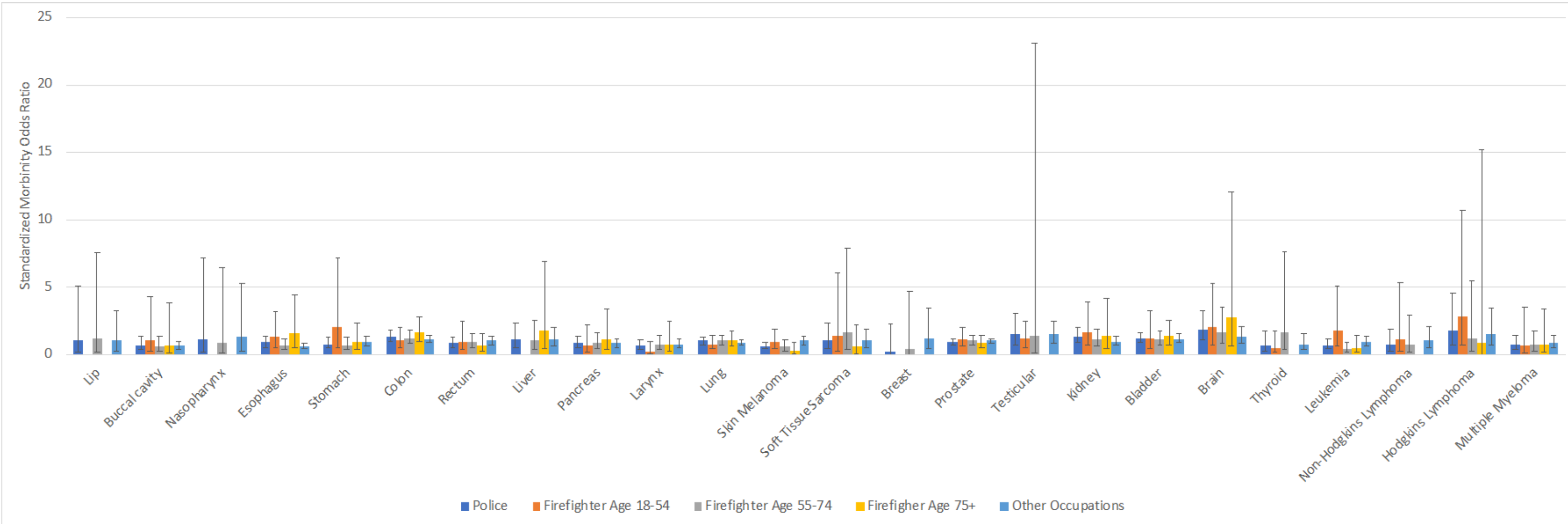

Figure 11. Standardized morbidity odds ratios, along with 95 % confidence intervals, by cancer types for firefighters (by age group), police officers, and all other occupations, adjusted for age at diagnosis and smoking status, adapted from Kang et al. (2008) Tables II and III.

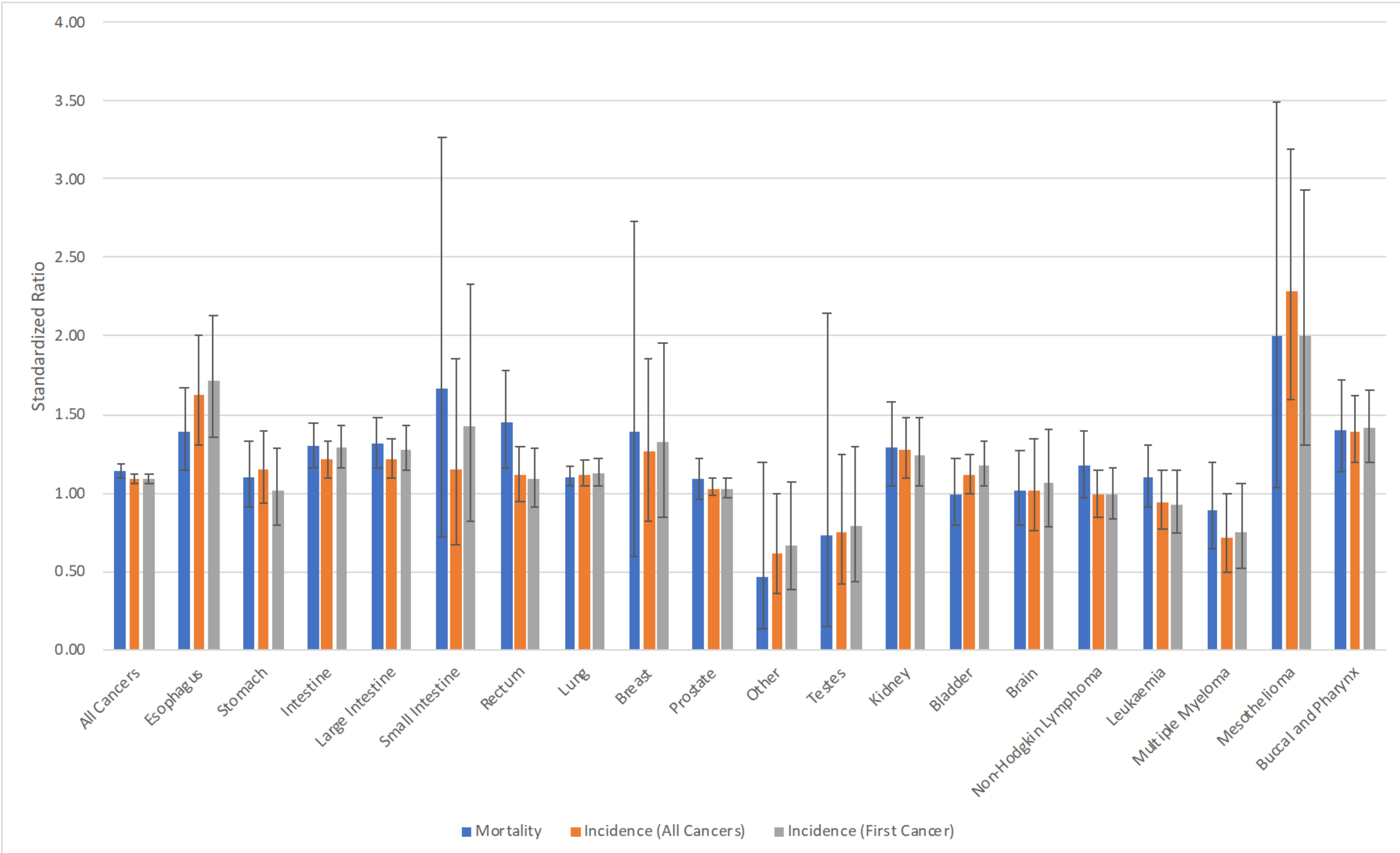

Figure 12. Standardized morbidity odds ratios and standardized incidence ratios, along with 95 % confidence intervals, by cancer types for firefighters, adapted from Daniels et al. (2014) Table 2.

6.2. Mental Health

Kessler et al. (2005) report the 12-month prevalence of DSM-IV mental disorders (from the Disagnostic and Statistical Manual of Mental Disorders) for the adult population in the US, based on the National Comorbidity Survey Replication. They found a 12-month prevalence of PTSD of 3.5 %. Kang et al. (2003) estimated the prevalence of post-traumatic stress disorder (PTSD) in Gulf War veterans (over 1995 to 1997) compared to a control group. The prevalence of PTSD was reported as 12.1 % for veterans compared to 4.3 % for the controls.

In a meta-analysis of 28 epidemiologic studies from across the world, Berger et al. (2012), found the prevalence of PTSD to be 10 % (8.1 % to 11.9 % 95 % CI) in 20 424 rescuers (defined as "ambulance personnel," "firefighters," "police officers exposed to a major disaster," and "other rescue teams"). The prevalence estimate is approximately three times that of the US adult population and roughly comparable to Gulf War veterans. Ambulance personnel were found to have exhibited higher rates than firefighters and police. The authors suggested this may be partly due to total call volume and having closer contact with the victims.

Berninger et al. (2007) tracked the prevalence of PTSD over a four-year period in firefighters (n = 10 074) who responded to the World Trade Center (WTC) 9/11 attack. They found the prevalence of PTSD increased from 9.8 % after one year to 10.6 % after four years. Wisnivesky et al. (2011) tracked WTC rescue and recovery workers (n = 27 449) over a nine-year period, including firefighters. (Protective services and military accounted for 48 % of the sample.) The cumulative incidence of PTSD for all, non-police, rescue and recovery workers was reported as having increased from 12.8 %, after one year to 31.9 % after nine years. (Panic disorders and depression rose from 5.0 % to 21.2 %, and 10.8 % to 27.5 %, respectively, over the same period.) The cumulative incidence of PTSD for NYC police officers was shown as being 2.5 % after one year to 9.3 % after nine years. (Berger et al. [2012] also noted a lower prevalence with police officers.) Wisnivesky et al. (2011) found additional health impacts post-9/11 for all workers, including asthma, sinusitis, gastro-oesophageal reflux disease, and abnormal spirometry. Bromet et al. (2016) report 9.7 % of surveyed responders (n = 3504) had PTSD 11 to 13 years post-9/11. (Police officers constituted 73 % of their sample.) Active PTSD was found to be correlated with respiratory symptoms, fair/poor health, fair/poor satisfaction, impaired friendships, and fair/poor social support.

The psychological effects from experiencing traumatic incidents can lead to other problems. Boffa et al. (2007) report a positive statistical link between PTSD and (1) suicidal ideation (incident rate ratio [IRR] = 1.026; 1.015 to 1.037 95 % CI) and (2) past suicide attempts (IRR = 1.052; 1.015 to 1.091 95 % CI) in firefighters in the United States. (An IRR of 1.0 implies no statistical association.) They also found a positive relationship with depression and suicidal ideation and past attempts. In a study of firefighters from New South Wales, Australia (n = 728), Harvey et al. (2016) demonstrated that exposure to traumatic incidents can lead to heavy drinking (> 42 alcoholic drinks per week). (They also found higher rates for retired firefighters.) Those who reported heavy drinking also reported PTSD (30.8 %) and depression (34.5 %). Martin et al. (2017) examined 2883 male firefighters in a large southern U.S. metropolitan area (pg. 45) to evaluate the link between alcohol use and suicide. Alcohol use was shown to be directly associated with higher suicide risk in firefighters, and indirectly, through an increase in depression and PTSD.

Gjerland et al. (2015) found of those rescue workers (n = 2922) of the 2011 terror attacks in Norway, 27.1 % of the police officers, 33 % of firefighters, and 61.8 % of unaffiliated volunteers reported unwanted/unexpected stress reactions after the rescue work was completed. The authors estimated that 2.4 % of police officers, 5.1 % of firefighters, and 14.5 % of unaffiliated volunteers reported sick-leave, because of the attacks, in the 11 months following the attacks. For firefighters, zero to seven days of sick-leave was taken.

6.3. Other Occupational Diseases

Heart disease is the leading cause of death in adults in the US, responsible for a quarter of all deaths.[14] Sudden cardiac death was the leading on-duty cause of firefighter deaths in 2016 (Fahy, et al. 2017), and heart disease was the second largest cause of all firefighter deaths, accounting for 41.7 % of fatalities by occupational diseases, based on the IAFF Summary of Death & Injury Surveys (see footnote 9). Emergency responders face several occupational risk factors for elevated blood pressure, including: irregular physical exertion, unhealthy diet, shift work, noise exposure, post-traumatic stress, and having high job demand with low decisional control (Kales et al., 2009). Other firefighting-specific factors include smoke exposure, heat, and dehydration (Soteriades et al., 2011). The prevalence of hypertension was found to be 23 % for career firefighters in 2000 (Soteriades et al., 2003). (Hypertension was found to affect one-third of all US adults in 2016 [Merai et al., 2016].)

Kales et al. (2003) evaluated NIOSH cases of 52 firefighter deaths due to coronary heart disease from 1996 to 2002. They found a positive correlation between coronary heart disease deaths and hypertension (odds ratio: 12.0; 5.8 to 24.9 95 % CI). In addition, they found correlations with age, smoking status, diabetes mellitus status, cholesterol, and prior diagnosis of coronary heart disease. In a comparison of on-duty coronary events of male firefighters in the U.S., based on NIOSH data, Geibe et al. (2008) report that firefighters who died had pre-existing risk factors such as smoking, hypertension, or a previous (non-fatal) coronary event. Geibe et al. (2008) found no statistical difference in risk factors between career and volunteer firefighters, although they did find that 34 % of the fatalities of volunteers were under the age of 45 years, compared to only 15 % of the career. (Kales et al. [2003] also found little statistical difference in risk factors between career and volunteer firefighters.)

Kales et al. (2003) also presented the percent of coronary heart disease deaths for firefighters and the general population by time-period of day (1996 to 2002) (see Figure 13). For the general population, the percent of deaths peaked slightly for the 6:00AM to 11:59AM time-period (about 33 %). It fluctuated between about 21 % and 25 % for the other time periods. For firefighters, the percentage peaked beginning the 12:00PM to 5:59PM time-period and remained equally elevated for the 6:00PM to 11:59PM period, at 39 %. Kales et al. explained that the relative incidence of coronary heart disease deaths generally follow call volume throughout the day when firefighters are most likely to experience physical exertion and stress.

[14] See: https://www.cdc.gov/heartdisease/facts.htm

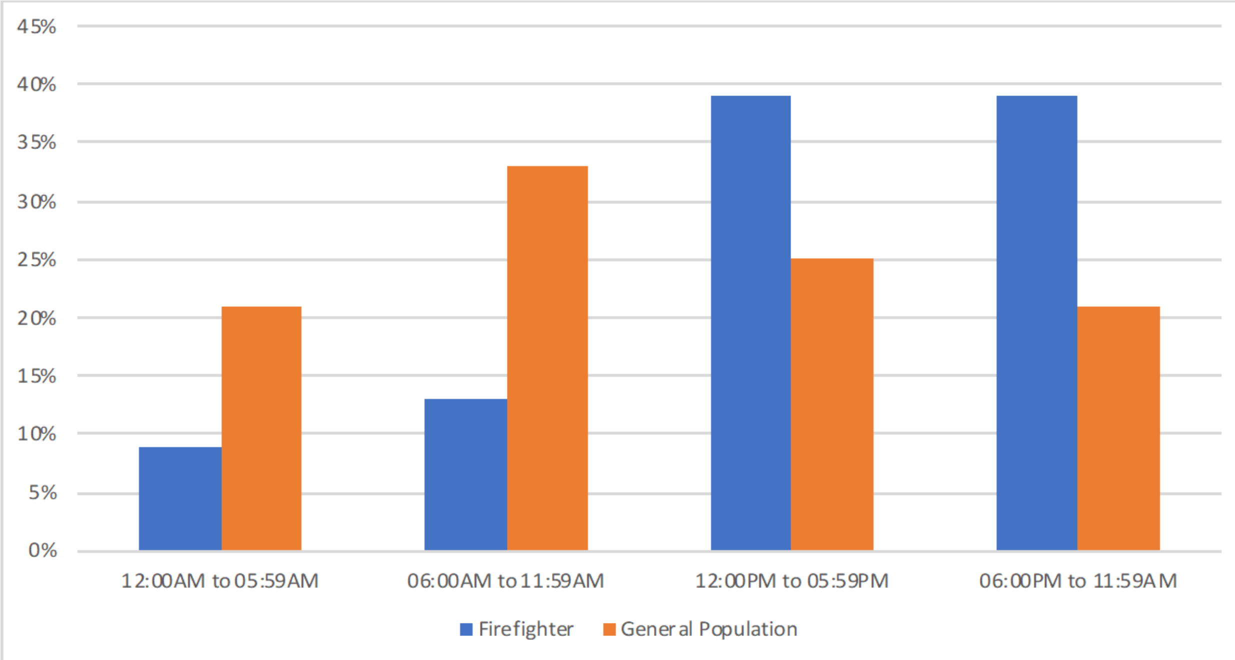

Figure 13. Percent of coronary heart disease deaths for firefighters and the general population by time period of day, adapted from Kales et al. (2003), Figure 2.

Kales et al. (2007) show that the risk of firefighter death due to coronary heart disease can vary by physical activity. They estimated that the odds of death due to coronary heart disease during fire suppression activities was 136 time greater (101 to 183 95 % CI) than nonemergency duties (based on national data). Alarm response (14.1; 9.8 to 20.3 95 % CI), alarm return (10.5; 7.5 to 14.7 95 % CI), emergency medical services and other (non-fire) emergencies (2.6; 1.8 to 3.9 95 % CI), and physical training (6.6; 4.6 to 9.5 95 % CI) were also shown to be activities of higher risk. While these activities represent opportunities for increased heart disease events, Kales et al. (2007) show these activities comprised 35 % of total time spent, with suppression accounting for only 1 %. Holder et al. (2006) evaluated 362 cases of retirement due to heart disability in Massachusetts (1997 to 2004), compared to 310 active firefighters. They found 42 % of the retirements were due to specific on-duty events. Similar to Kales et al. (2007), Holder et al. (2006) found a marked increase in the odds based on activity. They reported an odds ratio of 51 (12 to 223 95 % CI) for fire suppression, followed by alarm response at 6.4 (2.5 to 17 95 % CI), relative to non-emergency activities. (Physical training, alarm return, EMS and other non-fire emergencies were not significant.)

While firefighters may have an elevated risk of heart disease, the literature is mixed in attributing mortality to occupational status. Several studies failed to find the firefighter occupation as a risk factor in mortality from heart disease. Hansen (1990) investigated the chronic health of a cohort of 886 firefighters in Denmark over 1970 to 1980. Over the 10-year period, Hansen (1990) found no statistical evidence of increased ischemic heart disease, nor any other disease that he assessed, compared to the control group (n = 47 694). Beaumont et al. (1991) studied the mortality of 3066 firefighters employed in San Francisco between 1940 and 1982. They reported the observed-to-expected rate ratio of heart disease (in general) for firefighters compared to the general population was significant at 0.89 (0.81

to 0.97 95 % CI), while the rate ratio for ischemic heart disease was not significant at 0.95 (0.87 to 1.04 95 % CI). Only the general category, diseases of the digestive system (1.57; 1.27 to 1.92 95 % CI), and individual categories, cirrhosis and other liver disease (2.27; 1.73 to 2.93 95 % CI) and accident falls (1.90; 1.18 to 2.91 95 % CI) demonstrated elevated mortality risks (see Figure 14). However, they reported lower firefighter mortality risks for tuberculosis, diabetes mellitus, diseases of the respiratory system (including acute respiratory infections and emphysema) when compared to the general population.

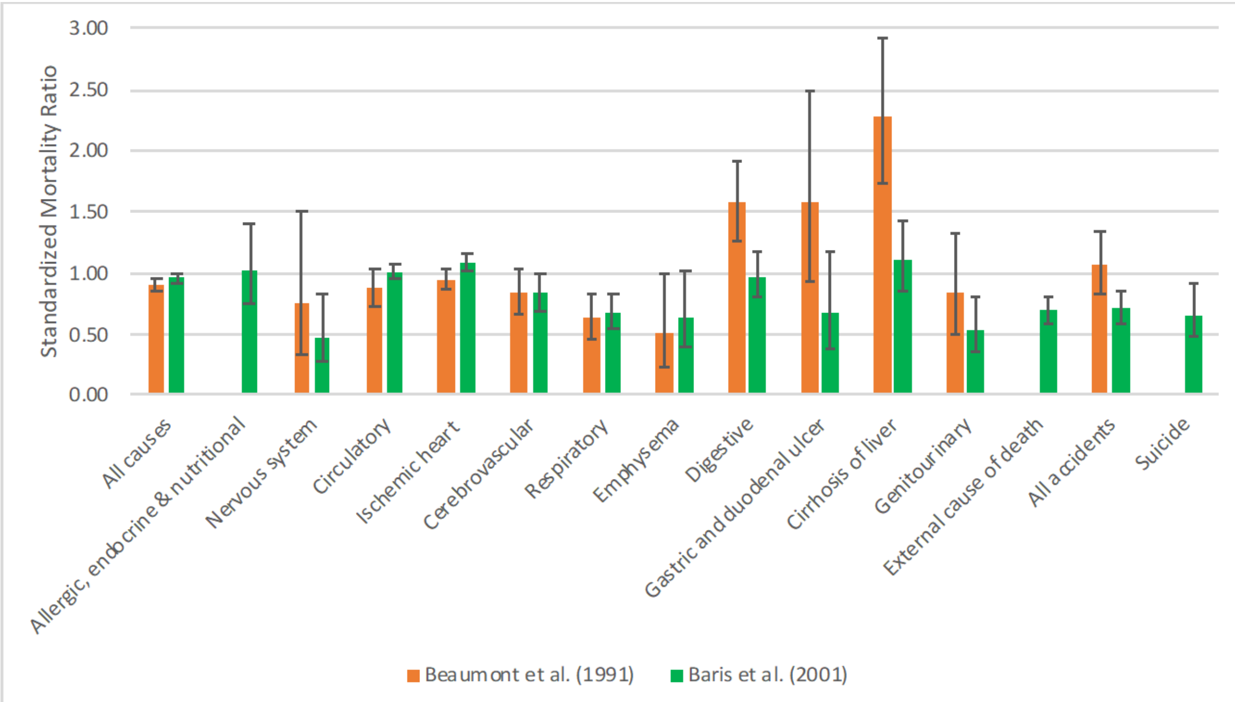

Figure 14. Standardized mortality ratios by major causes, and 95 % confidence interval, of death adapted from Beaumont et al. (1991) Table III and Baris et al. (2001) Table II (cancers excluded).

Guidoitti (1993) examined two cohorts of 3328 total firefighters in Alberta who were active from 1927 to 1987. While he found evidence of increased risk for cancers for firefighters, he did not find an association for heart disease or chronic pulmonary disease. Glueck et al. (1996) assessed the coronary heart disease risk of a cohort of 806 Cincinnati firefighters from 1984 to 1995. They concluded that coronary heart disease in firefighters can be attributed to risk factors such as smoking, obesity, family history, and blood pressure, but they did not find occupation to be a factor.

Rosénstock et al. (1990) compared the respiratory health of firefighters, employed between 1945 and 1980 in fire departments in the northwest, with two control groups: US population and police officers (based on NIOSH data). The comparison with police officers was done to account for a possible 'healthy worker effect' in emergency responders (i.e., that responders are selected from a healthier sub-population than the general population). They found both firefighters and police officers had lower standardized mortality ratios (SMR) for respiratory mortality. The SMR for all causes for firefighters was 82 (77 to 87 95 % CI) and for police officers 83 (75 to 91 95 % CI). However, in a direct comparison between the two groups, the

SMR was 87 (83 to 105 95 % CI), supporting the healthy worker hypothesis. (Demers et al. [1992] expanded this work to include other health effects and reached a similar conclusion.)

Choi (2000) suggests the healthy worker effect may confound the relationship between heart disease and firefighting due to the recruitment of firefighter candidates specifically without diabetes. Choi (2000) evaluated 23 prior studies that correlated firefighting with heart disease. Of the 23, 16 studies reported no association; however, after his reassessment, he concluded 4 of the 16 demonstrated evidence of a positive correlation, after accounting for the healthy worker effect.[15] Schermer et al. (2010) compared the lung function and health of (501) firefighters of a South Australian metropolitan department to the (1324) general population and found better overall general health, lung health, and mental health in the firefighter sample. Schermer et al. (2013) extended this work with a three-year follow-up and showed a decline in lung function in firefighters for those who reported incompliance of their respiratory protection.

Baris et al. (2001) evaluated the mortality of a cohort of 7789 Philadelphia firefighters, employed over 1925 to 1986. They observed a higher risk of some cancers and ischemic heart disease, but for the non-cancer causes of death, the estimated risks were either not significant or the risks were lower than US white males (see Figure 14). The standardized mortality ratio for ischemic heart disease was 1.09 (1.02 to 1.16 95 % CI). When broken-out by duration of employment (9 or less years, 10 to 19 years, 20 or more years), ischemic heart disease was significant only for those fatalities occurring in firefighters with 10 to 19 years of employment (1.35; 1.21 to 1.49 95 % CI). Lower standardized mortality ratios were estimated for all causes (includes cancers), nervous system disease, cerebrovascular disease, respiratory disease, genitourinary disease, external causes of death, all accidents, and suicide.

6.4. Firefighter Productivity

While injuries have direct financial impacts, they also can cause ripple effects that can impair the proper functioning of a business or workforce. Someone working with an injury may be less effective or may require more absences, hurting the overall productivity of a workforce. A long-term injury may also mean having other employees cover the lost time, pick up projects above their normal workload, or require the hiring and training of new temporary or permanent staff. Wranik et al (2017) examined the impact of occupational cancer on productivity in Canada using workers' compensation claims. An estimated $1.2 billion (Canadian) was lot in total due to occupational cancer from 1996 to 2013. Firefighter cancers were broken out in the model but found to be statistically insignificant ($p > 0.1$) in the estimation model.

Zaloshnja et al. (2006) focused on all injury within the United States and used Input-Output modeling to estimate the effect of reduction of injuries on employment and GDP. Firefighter injuries were not broken out in the model and the effects of injuries were broken into direct, indirect, and induced effects as a result of a 38 % decrease in injury rate from 1993 to 2002. After adjusting for under-reporting of injuries, Zaloshnja et al. (2006) arrived at an estimate

[15] Six of the 16 are cited in this section—Hansen (1990), Rosénstock et al. (1990), Beaumont et al. (1991), Demers et al. (1992), Guidotti (1993), and Glueck et al. (1996). Of the six, Choi (2000) reclassified only Hansen (1990).

of an increase in GDP of $35 billion, or 9 % of the average annual GDP increase from 1993 to 2002.

Literature directly linking firefighter injury to decreased productivity (response time, fire ground effectiveness) is scarce. Some studies have looked at issues that could be indirectly tied to firefighter productivity loss due to injury though. Dennison et al (2012) examined the relationship between fatigue and firefighter performance on a simulated fire ground test (SFGT). The study had multiple objectives; the one most relevant to the current research put 12 career firefighters through a training exercise before going through a SFGT and compared the results to a baseline SFGT for the same firefighters. Based on measures of time to complete, heart rate, and blood lactate, fatigue had a significant impact on overall performance. Time to complete was increased by 9.6 % with a heart rate increase of 4.1 %. No significant change in blood lactate was found.

While not directly tied to firefighter injury, injuries to firefighters may force departments to use backfill time (Tridata 2005). This can lead to overtime shifts that can induce fatigue in the firefighter(s) backfilling for the injured person with the NFPA reporting 5 % of injuries as being a result of exhaustion or fatigue (Karter 2012), compounding the possibility of shift related fatigue (Paley 1994). The role of staffing and fatigue are mirrored in focus groups of fire service employees asked about the greatest impact of musculoskeletal injuries (Walton et al 2003). A field-based intervention in Sullivan et al. (2017) found that those using a Sleep Health Program experienced a decrease in reported disability days (46 %) and that firefighters who attended education sessions as part of the program had a reduced likelihood of filing at least one injury report (24 %). Other firefighter specific investigations into the effects of fatigue can be found in Barger et al. (2015) (finding 37.2 % of firefighters show symptoms of sleep disorders), Moore-Merrell et al (2008) (finding 26.2 % of firefighter injuries are a result of a cluster including fatigue) and Barnes (2000) (general finding of sleep disruptions and exacerbating fatigue). A general overview of sleep related effects is found in Krueger (1989).

None of the above studies on firefighter fatigue and injury attempted to tie their results to any economic impacts (direct or indirect) but can serve as a basis for doing so. One means for quantifying the effect of productivity loss of a firefighting unit (department or shift) due to firefighter injuries is to determine the effect of injuries on response time of the unit and model how much additional damage is accrued over that period compared to a base response time for an assumed fully healthy fire department. (However, this approach only captures loss of productivity associated with fire calls.) Response time is used over time at fire ground since, for most structural fires, once suppression operations begin on site fire growth is typically halted. Sources for the dollar cost per minute of response time are Challands (2010) which estimated 4000 New Zealand dollars damage (in 2009) per minute of response time. After conversion this translates to (2018 USD) $3045.8 per minute of response time. An older source for US response time is Ignall et al. (1979). Converting their estimate of $1000 in 1978 to 2018 USD the loss per minute of response time is $3872. This is roughly in line with Challands (2010). Furthermore, the Fire Brigades Union (No Date) estimates that there would be a 20 % increase in fire-related deaths per annum with a five-minute increase in attendance time and a 7 % decrease in fire-related deaths with a five-minute reduction in attendance time for Britain.

No literature was found linking firefighter injury to increases in response time. Means of achieving an estimate are available though. Using NFIRS data as a time series it may be possible to determine the effects of overtime (no literature found, analysis would be an attempt to determine if a relationship between response time and overtime exists) and understaffing (based on findings in Claxton and Hurt (2000)) on the response time variable. While not a direct measure of the effects of injury, it would serve as a proxy of the anticipated effects of an injury within the responding station.

7. Discussion

This report identifies, summarizes, and evaluates the available data and the literature describing the economic costs associated with non-fatal firefighter injuries, illnesses, health exposures, and occupational disease resulting from line-of-duty activities. There are significant data challenges that prevent the full accounting of the economic consequences resulting from these negative health outcomes. Data gaps exist, largely due to latency issues, in capturing the incidence and economic consequences associated with firefighter cancer and other occupational diseases, including post-traumatic stress injuries.

Data Collection Needs:

- Tracking incidence of occupational disease (and equivalent for volunteer firefighters) and long-term health consequences
    - Data can help establish links to exposure for long term disease
    - To establish links requires better and more consistent reporting of incidents
- Better understanding of mental health and post-traumatic stress injuries, impact on fire departments, and direction of future trends
- Better understanding of costs related to:
    - Direct and indirect cost data specific to firefighting activities
    - Injury litigation and backfill

If better quantification and annual tracking of firefighter injuries, illnesses, health exposures, and occupational disease are to occur, improvements in data collection are needed. Because data collection efforts require time and resources, such efforts are likely only sustainable if the information derived from these efforts are aligned with incentives for their collection—i.e., the effort of increased data collection should be at least proportional to its usefulness to fire departments. Incentives need to be identified and articulated, particularly for those responsible for the data entry, and the incentives should be of value to company commanders, for example.

Incentives for increased data collection:

- To reduce the frequency and severity of injuries, illnesses, health exposures, and occupational disease

- To improve cost management by establishing industry injury cost benchmarks. This data can inform discussions with decision makers. Fire departments can compare costs to costs found in the report to see how injuries and costs compare with peers.

- To estimate return-on-investment on activities and equipment to enhance firefighter health (e.g., health and well-being programs, training, PPE, fire prevention efforts)

- To create friendly competitions between battalions (e.g., who has the ‘best’ incident reports) or to provide recognition at national conferences

Improving the frequency and consistency of data collection efforts requires mechanisms or tools to reduce barriers of data entry, including leveraging pre-existing systems to reduce the burden on resources. For example, NFORS automates real-time data collection through connection with pre-existing CAD systems, eliminating touch points, data entry duplication, and error, while providing enhanced data analytics and visualization capabilities for departments. The Fire Exposure Module allows firefighters to document and track incident and health exposures, fully integrated with CAD data, over their career.

Mechanisms to Increase Data Collection and Early Warning:

- Use of pre-existing systems/tools through following channels:
    - NFORS & Fire Exposure Module
        - Integrated with CAD
        - Includes physical and behavioral health exposures
        - Linkage with National Cancer Registry
    - NFIRS
        - Fire Service Casualty Module
    - CAD
        - Increase coverage to include more metro areas
    - Workers compensation reports of injuries

- Link hospital discharge data with industry and occupation data[16]

- Regular health screenings

[16] E.g., see Taylor and Frey 2013.

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