

A Multi-national Survey of Low-Energy and Smoking Materials Ignition Fires

Austin Anderson, Department of Mechanical Engineering, University of Texas at Austin, 204 East Dean Keeton Street, Austin, TX 78712, USA

Marc Janssens, Center for Nuclear Waste Regulatory Analyses, Southwest Research Institute, 6220 Culebra Road, San Antonio, TX 78238, USA*

Received: 21 June 2015/**Accepted:** 24 November 2015

Abstract. The three-part study described in this paper involved a detailed evaluation of fire statistics from four countries to compare the number of deaths and injuries from structure fires started by a small open flame ignition source to casualty counts from fires started by smoking materials. First, a qualitative multi-national comparison of low-energy and smoking materials ignition fires is made based on fire statistics obtained from the U.S., the U.K., Japan, and Finland for the period between 2002 and 2012. From this comparison it can be concluded that, compared to the other nations, the U.K. appears to have more of a problem with smoking materials ignition fires resulting in fatalities; and that Japan appears to have appreciably more smoking materials ignition fires, but not fatalities from such fires, than the other nations. A more detailed quantitative analysis is then performed to examine the contribution of low-energy (match, lighter, space heater, etc.) versus smoking materials (cigar, pipe, cigarette, etc.) ignition to the U.S. fire problem. An attempt was made to address two issues with the U.S. NFIRS database, i.e., the fact that it is based on a voluntary sample of U.S. fire department incident reports and that many of the data categories relevant to the present study contain unknown fields. From this analysis it is apparent that smoking materials ignition fires tend to more commonly result in fatalities than low-energy ignition fires, while the overall volume of low-energy ignition fires and corresponding losses and injuries are greater. Finally, a logistic regression model is presented that can be used to predict the probability that a fire resulting in a fatality was started by low-energy ignition based on the age and race of the victim, the item first ignited, and the season in the year when the fire took place. The model indicates that older persons are generally more susceptible to perishing in a fire resulting from smoking materials ignition rather than low-energy ignition.

Keywords: Fire statistics, Logistic regression model, Low-energy ignition fires, Open flame ignition fires, Smoking materials ignition fires

1. Introduction

This paper summarizes the results of an examination of low-energy and smoking materials ignition fires in the U.S., the U.K., Japan, and Finland. It seeks to enlighten the reader regarding various resources for fire statistics, while providing

* Correspondence should be addressed to: Marc Janssens, E-mail: mjanssens@swri.org



more in-depth presentations of fires, fatalities, and casualties resulting from fires whose heat source of ignition was either low-energy or smoking materials.

For the purposes of this paper, low-energy ignition fires are referred to as fires whose source of ignition was a lighter, a candle, a match, or some form of space heater. The intent was to capture fires that are started by a small non-smoldering ignition source while maintaining comparability of ignition source strength between the nations examined in the study. Smoking materials ignition fires are considered any sort of fire ignited by smoking materials, i.e., a pipe, cigar, or cigarette.

The study discussed in this paper was partly motivated by the recent change of Technical Bulletin 117, which is the State of California's standard for upholstered furniture flammability. Previously the standard required that filling materials pass an open flame test. The new standard, TB 117-2013, only specifies a smoldering resistance test for cover fabrics and filling materials. Consequently, the main objective of the study was to evaluate the fire statistics from different countries and determine up to what extent structure fires started by a small open flame ignition source contribute to the number of fire deaths and injuries, in particular compared to the contribution from structure fires initiated by smoldering ignition sources.

The paper consists of three sections. In the first section, the databases and datasets used in this paper's fire statistics are outlined. In the second section, international comparisons of fire statistics are discussed, including the problems of performing solid statistical analyses with fire data internationally. Additionally, a brief presentation of low-energy and smoking materials ignition fire data in the U.S., Japan, the U.K., and Finland is given, and qualitative comparisons made. The third section consists of a closer examination of U.S. low-energy and smoking materials fire data, along with a statistical analysis examining the question, "Are there any statistically significant factors differentiating smoking material and low-energy ignition fires, in particular in terms of fatalities?"

2. Datasets used

The datasets used in this paper are primarily derived from four primary databases: The National Fire Incident Reporting System (NFIRS) from the United States, The Great Britain Incident Recording System (IRS), the National Fire Incident Database run by the Fire and Disaster Management Agency of Japan, and the Statistical Data System for Finnish Rescue Services (PRONTO).

The U.S. data used in this paper comes directly from public data release files of NFIRS, a voluntary database of reported fire incidents maintained by the United States Federal Emergency Management Agency (FEMA). It captures sizeable amounts of fire data on a yearly basis, at various levels of resolution depending on the type and severity of fire reported. Such details can include basic information such as property use, incident (call) type, alarm and arrival times, and more detailed fire information such as area of origin, items first ignited, heat sources, etc. For fires resulting in injuries and fatalities, additional information is provided

regarding details such as injury type, activity at time of injury, etc. More details regarding information provided by the NFIRS database can be found in the NFIRS reference manual [1].

The United Kingdom data used in this paper comes from statistical abstracts released by the Department of Communities and Local Government (DCLG) in the United Kingdom [2–8]. These statistical abstracts, Fire Statistics United Kingdom 2008 and earlier, Fire Statistics Great Britain 2009 and later, are compiled using data gathered from the Fire Incident Recording System, and, prior to 2008, the Fire Data Report System. The Fire Incident Recording system of Britain gathers much of the same basic data as the NFIRS system, but has comprehensive coverage of all reported fires in the United Kingdom, and past 2009, just Great Britain.¹ Additionally, the system notably includes area damaged in square meters as a field. More information about the form of fire data gathered and the questions that can be answered by it are available from the incident recording system's documentation [9].

The Japan data used in this paper comes from a set of tables compiled for the authors by Ai Sekizawa, using the Fire and Disaster Management Agency of Japan's National Fire Incident Database. The database contains all reported fires occurring in Japan, with attribute data for incidents being at least as 'rich' as those found in NFIRS and Great Britain's IRS. However, due to language barriers in the literature, a thorough discussion of the database, its contents and attributes was unable to be located.

The small amount of Finnish data featured in this paper comes from Finland's national fire incident database PRONTO. It likewise features attribute recording at least as rich as NFIRS and Great Britain's IRS. Additionally, the database is comprehensive, containing all reported fire incidents for the nation of Finland.

In addition to the four databases mentioned above, basic aggregate fire statistics for many nations are compiled by the World Fire Data Centre (WFDC) maintained by the Geneva Association. Their reports include estimates of the total numbers of fires, losses, and injuries and fatalities associated with fires for many developed nations [10]. While this database was not used directly in the figures and tables developed for this paper, it bears mentioning as the only endeavor consistently involved in gathering international fire statistics.

3. International Comparisons of Fire Statistics

International comparisons of fire statistics are fairly common, but virtually always qualitative. The reason lies in the fact that actual reporting definitions for fire incidents can vary widely from nation to nation. Perhaps the most comprehensive examination of these reporting differences, along with efforts to standardize reporting across the European Union was compiled by Hocken [11]. This report provides a very thorough history of efforts toward standardization of fire report-

¹ Although past 2009 fire incidents in Northern Ireland have been excluded from the U.K. statistics, the comparisons between nations in this paper cover the period from 2002 to 2012 and the fire statistics for Great Britain are therefore assumed to be representative of the U.K.

ing across EU member nations, in addition to an analysis of an online survey disseminated to EU nation organizational entities in charge of their nations' respective fire statistics, for those nations that had such an entity. This online survey identified various inconsistencies in reporting across EU member nations, and concluded that additional standardization was required before solid comparisons could be made.

Problems in analysis due to these reporting differences are further compounded if fire incidence rates are desired as a function of, say, population, since demographic and census data for various nations can also vary widely in terms of availability and information gathered. These problems tend to cause analysts to shy away from a solid quantitative statistical assessment based solely on international statistics, and thus explain the generally qualitative nature of these comparisons.

Regardless, many international comparisons have been made over the years. Sekizawa compared elements of fire losses between the U.S., the U.K., and Japan in 1991 [12], and Hall compiled a series of reports providing brief comparisons of the U.S. with other nations along various metrics such as extent of flame spread, fire death incidence, smoke alarm prevalence, and monetary fire loss rates [13–15]. The USFA has also produced a report on international fire death rates using information gleaned from the WFDC, which concluded that the U.S. has improved considerably with respect to other developed nations in bringing down its fire death incidence rate [16].

4. Handling of U.S. NFIRS Data

The U.S. NFIRS database suffers from two problems not prevalent in the other nations' data. First, because it is a voluntary sample of fire departments in the U.S., raw counts of data derived from NFIRS substantially underestimate the national U.S. fire problem. Additionally, many of the relevant categories for structure fires, such as item first ignited or heat source of ignition, include both unknown and partial unknown fields. An example of a relevant partial unknown in the context of this paper would be "Heat from open flame or smoking materials, other."

There are two issues necessitating proper handling of these unknowns. First, for the general reporting aspects of the first two sections of this paper, exclusion of the unknown fires would bias the proportions of low-energy and smoking materials fires in accidental home fires. Second, for the statistical analysis of the NFIRS data in the latter part of the paper, excluding those fires with unknowns would both bias results and reduce the sample tremendously, and simply including the "unknown" field for each relevant category in a regression assumes that all fires containing "unknown" fields belong to explanatory variable patterns explicitly separate from the "known" variable patterns, which is untrue.

These issues with the U.S. NFIRS database have been known for almost as long as it has been in service. In 1989, Hall and Harwood published a paper detailing what is referred to as the "National Estimates" approach [17]. This

approach, which has been used from the mid-1970s up to today, attempts to address both the underestimation problem and the unknown problem in the NFIRS database. The underestimation problem is addressed using the National Fire Protection Association’s (NFPA) national fire brigade survey, which supplies unbiased marginal estimates of various aspects of the U.S. fire problem yearly using a stratified random sample of U.S. fire departments. These marginal estimates supply a “scaling factor” between the NFIRS data and the national totals that corrects for the underestimation in NFIRS. The unknown problem is handled by apportioning the unknowns in a given category to the known fields of that category proportionally. Generally this step is accomplished using an iterative proportional fitting procedure, see for example [18].

For this paper, the underestimation in raw counts is handled in the same manner as “National Estimates,” and uses the proportion of NFIRS fires with unknowns apportioned multiplied by the marginal total estimates from NFPA reports to get reasonable raw counts of fires belonging to a particular field, here low-energy and smoking materials ignition fires. For example, the scaling for the number of smoking materials ignition fires is done as follows:

$$\begin{aligned} & \frac{(\# \text{ of Smoking Material Residential Structure Fires})_{NFIRS}}{(\text{Total } \# \text{ of Residential Structure Fires})_{NFIRS}} \\ & \quad \times (\text{Total } \# \text{ of Residential Structure Fires})_{NFPA} \\ & = (\# \text{ of Smoking Material Residential Structure Fires})_{U.S.} \end{aligned} \tag{1}$$

where the *NFIRS* subscript denotes the NFIRS estimate of all residential structure fires and those started by smoking materials, the *NFPA* subscript denotes the NFPA estimate of residential structure fires for the U.S., and the *U.S.* subscript denotes the national estimate of residential structure fires started by smoking materials.

Finally, apportioning of unknown fields in this paper is handled using multiple imputation, specifically using the EMB algorithm of Honaker and King [19]. Multiple imputation is a technique of approximating missing values in data based on the observed values. The “multiple” term arises because the general strategy of the technique is to produce multiple “complete” data sets with the unknowns filled in with approximated values, then to perform relevant complete data analysis on each of these data sets, then to recombine the results according to a set of rules derived by Rubin [20]. Such an approach allows the uncertainty from the imputation of the data to be propagated through subsequent analyses. For reference, the combination rules derived by Rubin in [20] are outlined below, where m is the number of imputation data sets, \hat{Q}_j is an estimate of a given quantity of interest and U_j is the variance associated with the estimate \hat{Q}_j :

$$\bar{Q} = \frac{1}{m} \sum_{j=1}^m \hat{Q}_j \tag{2}$$

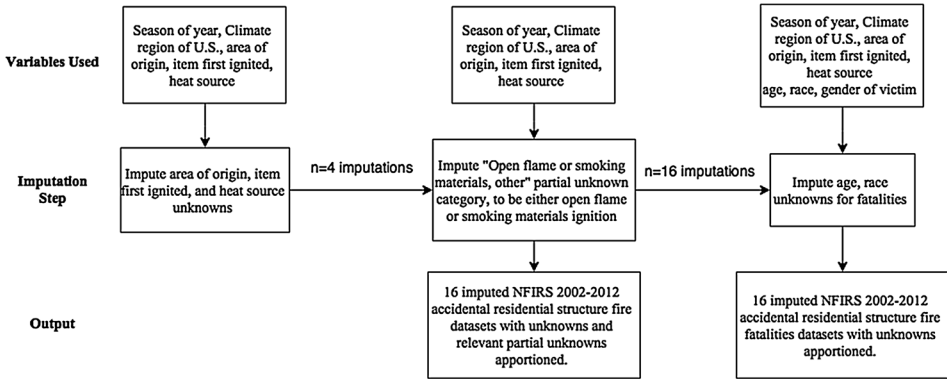


Figure 1. Imputation process applied to U.S. NFIRS data to apportion unknowns.

where \bar{Q} is the combined estimate from the imputations. Additionally, the within-imputation variance, \bar{U} , is calculated as:

$$\bar{U} = \frac{1}{m} \sum_{j=1}^m U_j \tag{3}$$

Next, the between-imputation variance, B , is calculated as:

$$B = \frac{1}{m-1} \sum_{j=1}^m (\hat{Q}_j - \bar{Q})^2 \tag{4}$$

Finally, total variance from imputation, T , of estimates is calculated as:

$$T = \bar{U} + \left(1 + \frac{1}{m}\right)B \tag{5}$$

Figure 1 supplies an overview of the multiple imputation process applied to the data in this paper. First, the unknown fields in area of origin, item first ignited, and heat source were imputed with the EMB algorithm using a model that included hour of day, season, climate region, area of origin, item first ignited, and heat source. Next, a second set of imputations was performed on a subset of the first set to apportion the partial unknown heat source category “open flame or smoking material, other” due to the impact this category could have on discussions in this paper. For the sections of this paper dealing with national comparisons, this set of 16 imputations on accidental residential structure fires was used in conjunction with NFPA marginal estimates. For the last section of this paper, an additional set of imputations were performed on the subset of accidental residential structure fires started by low-energy or smoking materials ignitions that resulted in fatalities, whereupon age, gender, and race were added to the original predic-

Table 1
NFIRS Confined Fire Incident Field Code Assumptions for Area of Origin, Item First Ignited, and Heat Source Categories

Confined fire incident code	Area of origin code	Item first ignited code	Heat source code
113	NA	76	12
114	NA	NA	81
115	50	NA	12
116	NA	NA	81
117	NA	NA	12
118	NA	96	NA

NA means that no assumption was made

tors in order to impute race of the victim. This set of imputations was then used for the logistic regression analysis.

There are two limitations imposed on the NFIRS data as a result of using multiple imputation. First, to render the imputation model reasonably identifiable for nominal data, various fields within the area of origin, item first ignited, and heat source of ignition categories had to be aggregated. Second, in order to help the imputation model resolve confined fire incidents, which traditionally do not have any values filled in for the aforementioned three categories, certain assumptions were made regarding fields for these incidents. These assumptions are outlined in Table 1. Confined cooking fires, incinerator overloads or malfunctions, and compactor fires were assumed to have “heat from operating equipment” as their heat sources. Confined chimney and flue fires, and fuel burner/boiler fires were assumed to have “heat from direct flame, convection currents from another fire.” as their heat source. Additionally, confined cooking fires were assumed to have “cooking material” as their first item ignited, while confined trash or rubbish fires were assumed to have “trash or rubbish” as their first item ignited. Finally, confined incinerator overload fires were assumed to take place in a “service area” for their area of origin.

5. Examination of Low-Energy and Smoking Materials Ignition Fires in the U.S., the U.K., Japan, and Finland

In the same vein as Sekizawa [12], data on fires ignited by low-energy and smoking materials sources were gathered where possible from the U.S., the U.K., Japan, and Finland. For the U.S., data was available from 2002 to 2012, with the caveat that the NFIRS system switched to a new version in 2000, and thus the 2002–2004 fire data is sparser compared to later estimates. For the U.K., data was available from 2002 to 2012, excluding the year 2009, estimates for which have been withheld by the U.K. due to one of their fire rescue organizations experiencing difficulties with switching to the Great Britain IRS. Japan data is available in limited capacity from 2002 to 2010, and comes from the authors’ correspondence with Dr. Ai Sekizawa. Finally, Finnish data for 2009–2012 was retrieved from the

PRONTO database and provided by Dr. Tuula Hakkarainen at the Technical Research Centre of Finland (VTT). Data for earlier years is also available but was not included because of a change in the reported fire statistics.

Prior to viewing the tables and figures in this section, a number of limitations regarding these comparisons must be discussed. First, there is some level of error attributed to reporting differences between the nations, depending on the actual differences in definitions between “space heaters,” “candles,” “matches,” “lighters,” and “smoking materials” across nations. Empirically, “space heaters” appears to have the most potential variation in reporting due to the ambiguity attached to its classification. Second, arson and suspected arson fires were excluded from all estimates, as the focus of this examination is on accidental fires. Third, for this analysis, smoking materials were defined in the following manner: For the U.S., cigarette, pip, cigar, or other smoking materials ignition; For the U.K., “Smoker’s materials” from Table 3 of the statistical abstract [8]; For Japan, cigarette ignition fires; For Finland, cigarette, other tobacco product.

Fourth, for this analysis, low-energy ignition fires were obtained from the countries’ statistics as fires ignited by the following: For the U.S., Version 5.0 NFIRS fires excluding mutual and automatic aid incidents, for which the heat source of ignition was matches, lighters, candles, or fires involving gas or liquid fueled lighters or some form of space heater as equipment involved. As a note, mutual and automatic aid incidents are where a fire department outside the jurisdiction of the responding fire department comes to help. Fire departments providing such “aid” also fill out an NFIRS incident entry describing their contribution with the note that they were supplying “mutual aid.” If these incidents are not excluded, then fires that required mutual or automatic “aid” will be double-counted or worse in estimates. For the U.K., low-energy ignition fires were obtained using fields from Table 3 of [8], where the fields are identified as involving cigarette lighters, matches, candles, or “space heating appliances;” For Japan, low-energy ignition fires were obtained from fires for which the “Type of Open Flame Ignition” was lighters, matches, candles, or space heaters; For Finland, low-energy ignition fires were obtained from fires for which the cause of ignition was classified as “Hot work, match, candle, or various fireplace related ignition sources (spark or firebrand, insufficient safety distance).”

Additionally, note that for Figure 2, open flame ignition fires are a subset of low-energy fires and refer to those fires for which the ignition source was classified as “candles,” “matches,” or “lighters” across all nations examined. These estimates are somewhat more reliable as the definition of “candles,” “matches,” and “lighters” is consistent across all nations examined.

Tables 2 and 3 provide yearly averages of residential structure smoking material and low-energy ignition fires for the U.S., the U.K., Japan, and Finland; in both raw numbers (Table 2) and percentages of total residential structure fires, fatalities, and injuries (Table 3), excluding injuries for Japan, which were not readily available. The values for the U.S., the U.K., and Japan in Tables 2 and 3 are based on the fire statistics for the years 2002–2010, excluding 2009. The values for Finland are based on the fire statistics for the years 2009–2012, since those for years prior to 2009 were not readily available in a form that could be compared

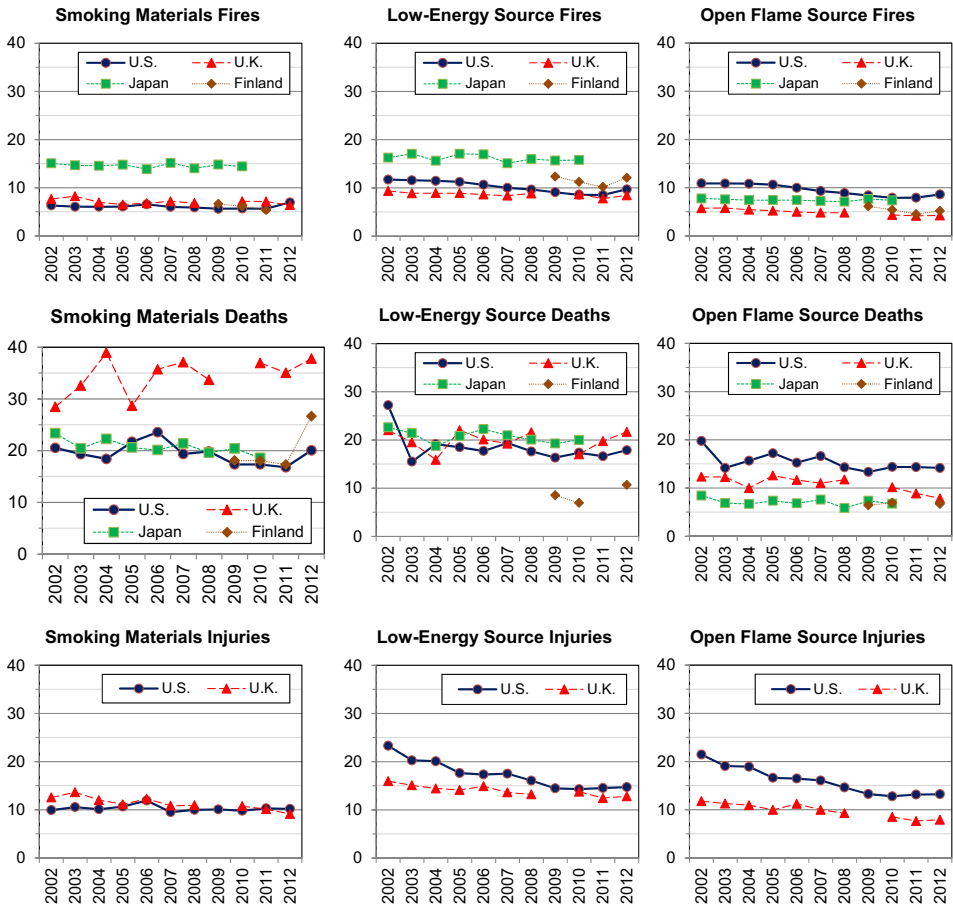


Figure 2. Percentage of 2002–2012 residential fires/fatalities/casualties, grouped by ignition source, for the U.S., the U.K., Japan, and Finland.

to the other nations. Table 2 supplies the reader with a sense of the scales of the fire problems among the nations. As expected, the U.S. has the highest raw counts, on account of its population. However, it is notable that, while fatalities appear to scale roughly proportionately to population among the nations, injuries and fire incidents do not, with the U.S. appearing to have significantly higher fire incidents involving smoking materials and low energy ignitions per 2010 capita than the other nations, but significantly lower injuries per capita. This discrepancy could potentially be linked with how the nations handle confined fire incidents, but without greatly enhanced details concerning other nations’ reporting tendencies in their respective databases, this issue cannot be explored further.

Table 3 displays the proportional contribution of fires where smoking materials and low-energy were identified as the ignition source to the overall number of res-

Table 2
Yearly Average Number of Smoking Material and Low-Energy Ignition Fires/Fatalities/Casualties for Residential Structure Fires in Four Countries

Nation	2010 population (millions)	Smoking materials			Low energy		
		Fires	Fatalities	Injuries	Fires	Fatalities	Injuries
United States	308.3	20,196	457	1259	33,934	433	2127
Great Britain	62.3	3159	102	1076	3881	59	1314
Japan	127.6	2544	240	NA	2835	241	NA
Finland	5.3	207	15	70	395	5	77

Table 3
Smoking Material and Low-Energy Ignition Fires/Fatalities/Casualties as a Percentage of Total Residential Structure Fires/Fatalities/Casualties in Four Countries

Nation	Smoking materials			Low-energy		
	Fires	Fatalities	Injuries	Fires	Fatalities	Injuries
United States	6.0	19.4	10.3	10.0	18.1	16.9
Great Britain	7.2	33.8	11.8	8.8	19.7	14.5
Japan	14.6	20.8	NA	16.2	20.9	NA
Finland	6.0	20.1	15.3	11.5	7.2	16.8

idential structure fires for 2002–2010 excluding 2009, for the U.S., the U.K., and Japan; and for 2009–2012 for Finland. From this table, it is apparent that smoking materials ignition and low-energy ignition fires are, proportionally, two times higher in Japan than in the other nations. Despite this disparity in fire incidents, their proportion of fatalities for both ignition source types is roughly comparable. Also notable is the fact that Britain appears to have a substantially higher proportion of fatalities from smoking materials ignition fires than the other nations.

Figure 2 expands on the content of Table 3, and provides the proportional contributions of smoking materials, low-energy ignition, and open flame ignition (a subset of low-energy) sources to the overall fire problems of the U.S., the U.K., Japan, and for a small set of data, Finland. One can see that in terms of the total proportion of fires, Japan stands above the other three nations considerably for smoking materials and low-energy ignitions. Also, the percentage of smoking materials, low-energy ignition, and open flame fires has been roughly constant across all of the nations, despite decreasing total numbers of fires.

Examining fatalities in Figure 2, it appears that smoking materials fires are contributing to fatalities at roughly the same rate in the U.S. and Japan as low-energy fatality fires, indicating they are uniformly more lethal than low-energy ignition sources, since they are a smaller proportion of the total fire contribution in these nations.

For the U.K., smoking materials ignition fires contribute almost a third of the yearly residential structure fire fatalities, a sizeable difference compared against the U.S. and Japan. To place this sizeable departure in perspective, examine Figures 3 and 4, which contain the fatality rates for the U.S., the U.K., and Japan per 1000 reported residential structure fires and per million population respectively (Figure 3 also includes a few data points for Finland). One can see that, per capita population, all three nations have roughly the same fatality rate, and that, per 1000 reported residential fires, the U.S. and the U.K. have almost identical fatality rates over the time period. This indicates strongly that the U.K.'s apparent outlier status in Figure 2 could arise as a result of three potential issues, or some combination thereof.

First, the U.K. truly has more of an issue with residential fire fatalities arising from smoking materials ignition that is disproportionately allocated compared to the U.S. and Japan. Second, reporting differences between the nations may cause the U.S. and Japan to appear to have better results here than the U.K., simply because more reporting options exist for ignition sources. For example, in the U.S. there are 37 different ignition source classifications available, while in the U.K. ignition sources are apparently collated into a more concise 12 categories. Finally, one should note that ignition source reporting between nations is to some extent driven by the standard operating procedures of fire investigators. Thus, if there exist appreciable systematic differences in operating procedures for fire investigators between, say, the U.K. and the other nations, then these differences will manifest between the nations' fire statistics. Unfortunately, the authors are unaware of any literature deeply examining the differences in fire investigation procedures internationally, and thus such an issue cannot be rigorously examined in this paper.

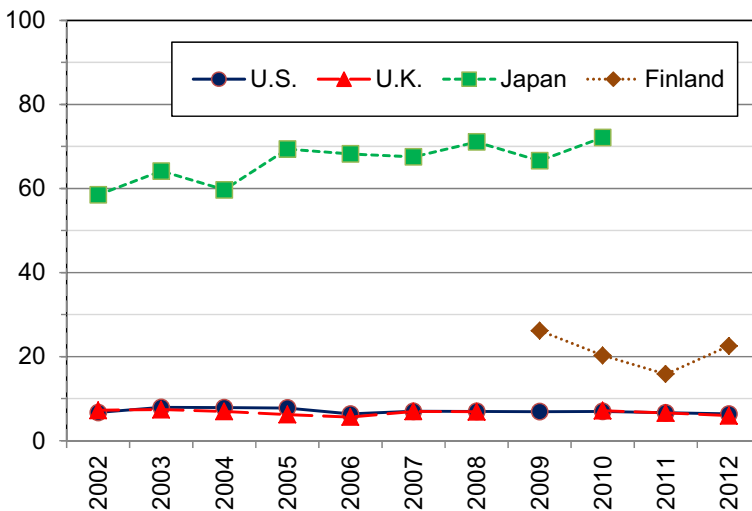


Figure 3. Yearly trend of fatalities per 1000 Residential structure fires for the U.S., the U.K., Japan, and Finland.

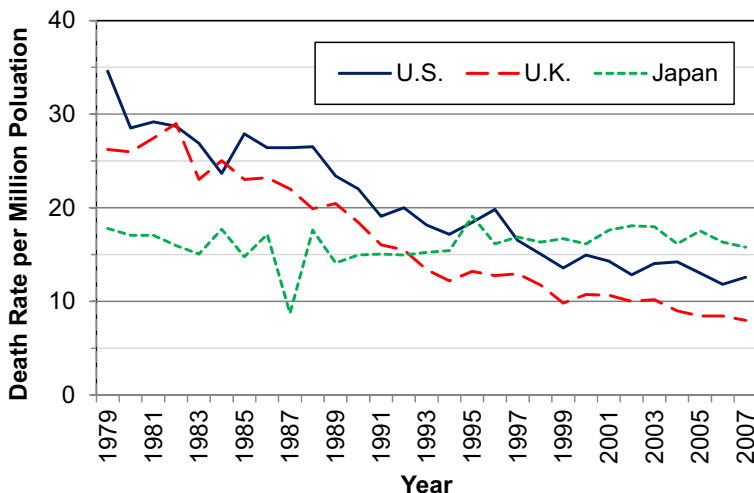


Figure 4. Comparison between the U.S., U.K., and Japan of per capita death rates due to fire for 1979–2007 from [16].

Note also, when examining Figure 3, that while Japan may appear much worse than the U.S. and the U.K., the high value observed is driven more by a low number of reported residential fires (a good thing!), when compared against the U.S. and Britain, than by a substantially higher number of fatalities. However, this apparently higher death rate is reflected somewhat in the per capita statistics in Figure 4, and likely arises as a result of Japan's disproportionately aging population compared to the U.S. and the U.K. This aging issue and its impacts on the fatality rates and fire problem of Japan have been explored extensively by Sekizawa [21, 22].

In addition, Figure 2 shows that for low-energy fire fatalities, the U.S., the U.K. and Japan almost look like the same nation in terms of contribution, with Finland landing substantially lower. Notably, for low-energy and open flame fatalities, all nations exhibit roughly similar trends in their proportional contributions.

Examining injuries in Figure 2, it is apparent that the U.S. the U.K., and Finland have roughly the same trends in their fire problem across all categories, with the U.S. exhibiting a higher proportion of injuries involved in fires originating from low-energy and open flame ignition sources.

One might consider the differences seen between the U.S., the U.K., Japan, and Finland with regards to smoking material ignition fires to be a function of differences in smoking prevalence between the countries. Figure 5 provides a graph that includes OECD health data for the U.S., the U.K., and Japan over the relevant time periods of the available fire data [23]. There is a small difference in smoking prevalence between the U.S. and the other two nations, but perhaps not enough of a difference to fully explain all the discrepancies. Additionally, the discrepancy between Japan and the U.K. is miniscule, but there is a sizeable difference in pro-

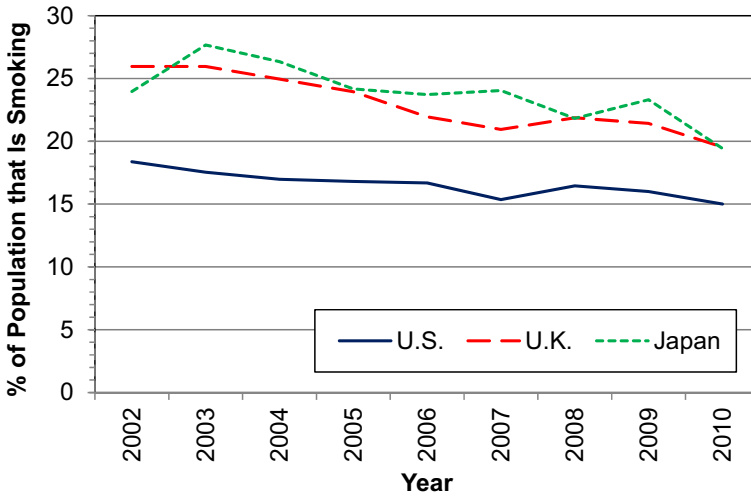


Figure 5. Smoking prevalence in the U.S., U.K., and Japan [22].

portional contribution between their fires and fatalities. One additional reason why the U.S. might fall below Japan and the U.K. could be the U.S.’s adoption of reduced ignition propensity (RIP) cigarettes, as discussed by Hall [24]. This could also explain the lower incidence of smoking material ignition fires in Finland compared to Japan.

Finally, when examining Figure 2, note that the absolute numbers of fires, fatalities, and injuries have been dropping over the 2002–2012 time period. The general flatness of many of the graphs in Figure 2 only indicate that the relative contributions of smoking materials, low-energy ignition, and open flame fires to the overall residential fire problem, which is improving, have remained essentially constant.

Table 4 provides an interesting glance into the top five items first ignited by average yearly fatalities, for smoking materials and low-energy ignition sources, for the U.S., the U.K., and Japan. From this table, one can see that, aside from a small amount of ordering and difference in relative severity, the same sorts of objects result in fatal fires regardless of ignition source, with smoking materials ignition fires being more associated with higher average fatalities. Also worth noting from Table 4 is the extremely strong association between upholstered furniture and bedding with smoking materials as regards average fatalities, shared commonly across the U.S. and the U.K. Japan has a similar problem with bedding and smoking materials ignition fires as the other two nations but lacks the upholstered furniture issue, likely due to cultural differences reducing the prevalence of upholstered furniture in Japanese households.

Table 4
The Top Five List of Items First Ignited in the U.S., the U.K., and Japan
by Yearly Average Count of Fatalities, for Smoking Materials and
Low-Energy Ignition Fires

United States		United Kingdom		Japan	
Item first ignited	# fatalities (avg/year)	Item first ignited	# fatalities (avg/year)	Item first ignited	# fatalities (avg/year)
Smoking materials ignition					
Upholstered furniture	147.9	Upholstered furniture	22.2	Bedding	104.9
Mattresses/bedding	107.9	Bedding	19.0	Floor materials	33.1
Others	56.2	Clothing	13.8	Others	28.7
Structural component/finish	33.8	Bed/mattress	9.2	Papers	28.2
Furniture/utensils (excl. upholstered furniture)	23.0	Paper/cardboard	5.4	Apparel	11.4
Low-energy ignition					
Mattresses/bedding	67.0	Clothing	14.2	Apparel	54.8
Structural component/finish	59.8	Bedding	7.2	Bedding	48.0
Upholstered furniture	59.5	Paper/cardboard	5.8	Petroleum	29.0
Others	54.6	Upholstered furniture	5.0	Others	25.0
Furniture/utensils (excl. upholstered furniture)	42.9	Petrol/oil products	4.2	Papers	21.9

U.S. and Japanese rates appear higher due to aggregation within categories

6. Examinations of Low-Energy and Smoking Materials Ignition Fires for the U.S.

As aforementioned, the NFIRS database suffers from a number of biasing issues related to the voluntary reporting underpinning it. Many fires go unreported due to either their small size or containment, and additionally many reporting fields are perhaps susceptible to differences in interpretation between various fire departments across the nation. The latter is illustrated by Table 5, which gives the (sometimes ambiguous) meaning for each of the NFIRS codes for the item first ignited field, as aggregated by the aforementioned imputation procedure. Additionally, in 2000, the USFA switched from NFIRS 4.1 coding to 5.0 coding, resulting in a lower reporting rate for a few years following 2000. Figure 6 exemplifies this reporting anomaly, indicating that a raw examination of NFIRS 5.0 fires, as recommended in [25], might produce misleading trends as increased reporting of fires produces the appearance of an increasing fire problem.

As a result of the above issue, numbers reported in this section are in the form of proportional contributions to the total fire problem Table 6 is an exception, and mentions yearly averages calculated according to the imputation procedures coupled with NFPA marginal totals outlined earlier. So for example, instead of reporting the raw number of structure fires in a given year for which the ignition source was identified as low-energy or smoking materials, the percentage of fires whose identified ignition source was low-energy or smoking materials is reported

Table 5
Items First Ignited NFIRS Code Legend

Item first ignited code	Meaning
0	Item first ignited, other
10	Structural component, finish
21	Upholstered sofa, chair
20	Furniture, utensils, not covered by 21
31	Matress, bedding: pillow, blanket, sheet, comforter
35	Wearing apparel on a person
30	Other soft goods and wearing apparel
50	Storage supplies
65	Flammable liquid/gas, accelerants
76	Cooking materials
81	Electrical wire, cable insulation
92	Book, magazine, newspaper, writing paper
95	Dust, fiber, lint, adhesives, residues (e.g. paint, resin)

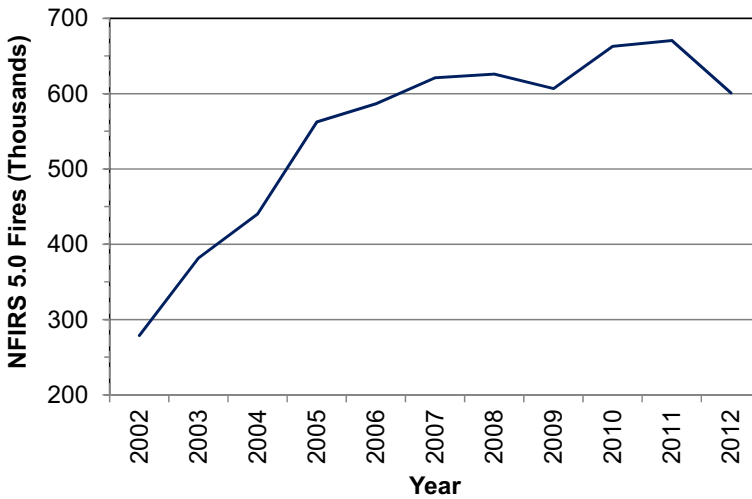


Figure 6. NFIRS version 5 fire reporting 2002–2012. (Shows how NFIRS participation picked back up after transition to version 5.0).

in this section. This approach circumvents the reporting issue, as the underlying contribution of various ignition sources to the total fire problem, in this section for structure fires, is expected to remain relatively constant among reporting units. In other words, although the raw total number of fires may be incorrect due to reporting issues, the relative contribution of subsets of the reported structure fire population to the total reported structure fire population remain largely consistent, provided that unknowns are apportioned reasonably.

Table 6
Top Ten Items First Ignited Sorted by Average Yearly Fatalities for 2002–2012 Fires, Fatalities, and Injuries for U.S. Low-Energy and Smoking Materials Ignition Fires

Low-energy ignition				Smoking materials ignition			
Item	Fires (average)	Fatalities (average)	Injuries (average)	Item	Fires (average)	Fatalities (average)	Injuries (average)
21	2021	147.9	250	31	3765	67	366
31	2505	107.9	316	10	6922	59.8	198.4
0	5486	56.2	235.1	21	1745	59.5	167.1
10	4941	33.8	122.4	0	5234	54.6	246.2
20	1233	23.1	83.7	20	4367	42.9	243.3
30	1086	22.4	70.1	30	4315	35.1	264.9
35	93	19.8	19.8	65	1446	27	165.1
65	451	12.7	53.4	76	1793	17.6	82.4
76	686	9.1	35.7	35	170	17.6	29.3
81	360	6.5	15.4	81	1121	16.6	30.3

7. Summary Views of NFIRS Data Comparing Low-Energy and Smoking Materials Ignition Fires

Figures 7 and 8 provide various summary views of the relative contributions of low-energy and smoking materials ignition sources to the total number of fires, fatalities, and injuries for 2002–2012 structure fires in the United States. Figure 7a–c examine the yearly contributions of these ignition sources to the overall fire problem, while Figure 8a–c examine the cyclical daily contribution of these ignition sources to fires, fatalities, and injuries, respectively.

From Figure 7a, it is apparent that smoking materials ignition fires are substantially less prevalent than low-energy ignition fires. Figure 7c indicates that the latter contribute many more injuries, though this difference in injuries has been decreasing with time. Additionally, it is readily apparent from comparing Figure 7b to the Figure 7a that smoking materials ignition fires are worse on a per fire basis.

From Figure 8a, it can be seen that time of day has relatively little impact on the contribution of low-energy ignition fires. However, there is a noticeable impact with regards to smoking materials fires, which experience an up-turn in prevalence between the hours of 9 pm and 7 am. Examining Figure 8b, it is interesting to note that there is a 6 h period of the day between 1 pm and 7 pm when the trend in fatalities between smoking materials and low-energy ignition sources separates. Finally, Figure 8c shows that both ignition sources exhibit the same trend in their relative contributions to injuries throughout the day, with low-energy ignition sources contributing roughly twice as many injuries as smoking materials ignition sources in the afternoon.

When examining Figure 9, note that the losses reported to NFIRS are fire-fighter estimates and therefore not guaranteed to be accurate. Also note that in

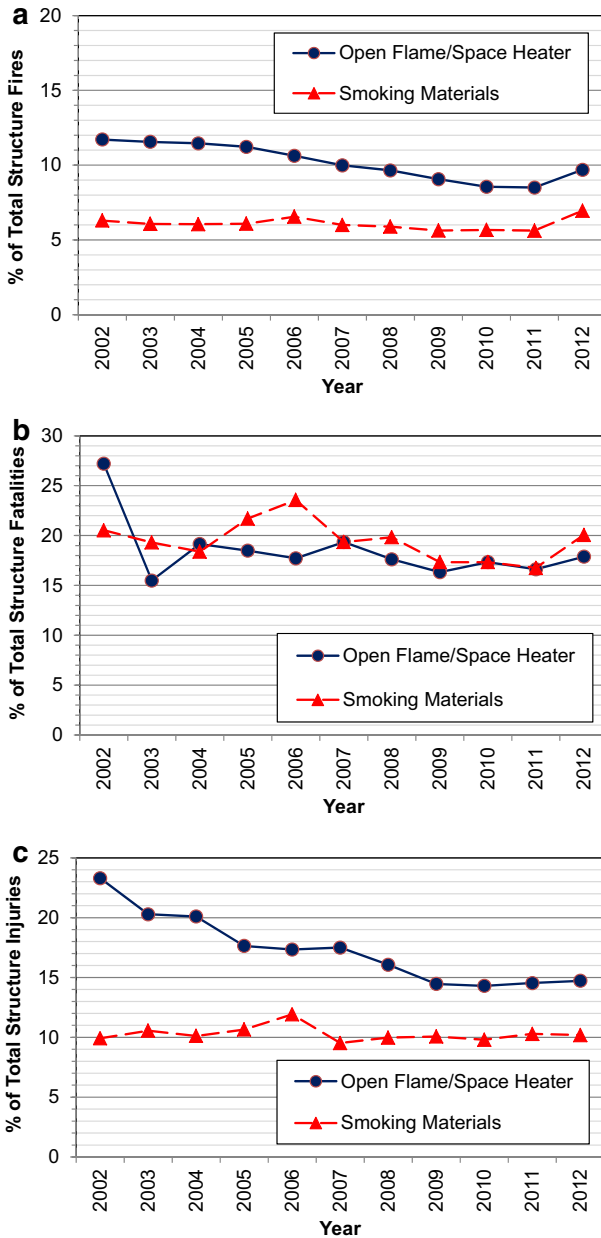
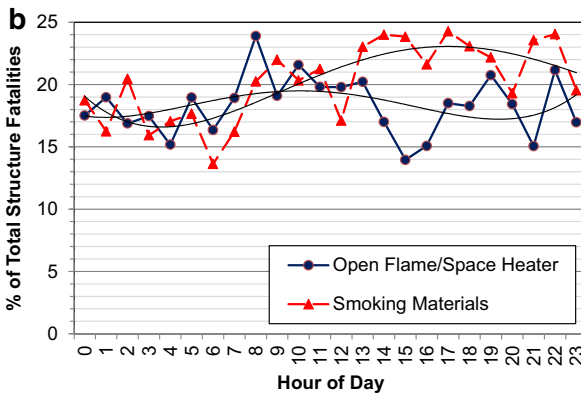
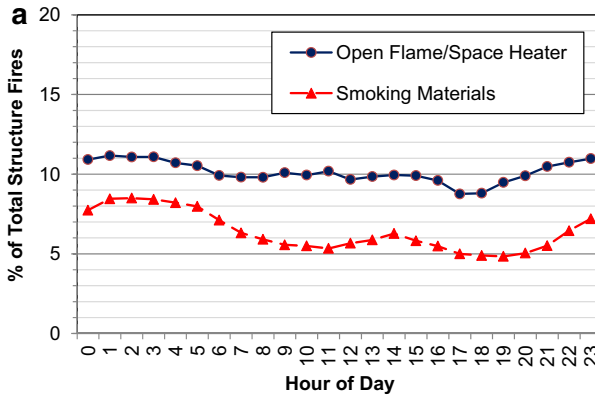
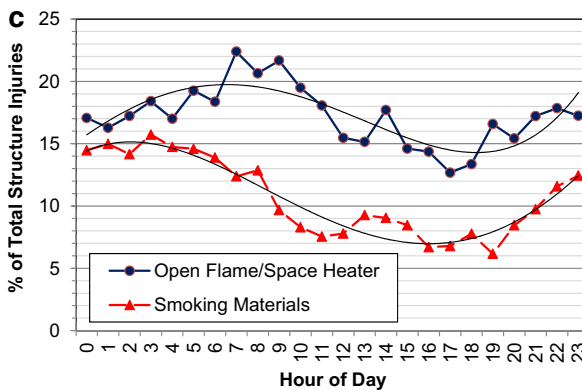


Figure 7. a Percentage of Total 2002–2012 U.S. structure fires grouped by ignition source. b Percentage of Total 2002–2012 U.S. structure fire fatalities grouped by ignition source. c Percentage of total 2002–2012 U.S. Structure fire injuries grouped by ignition source.

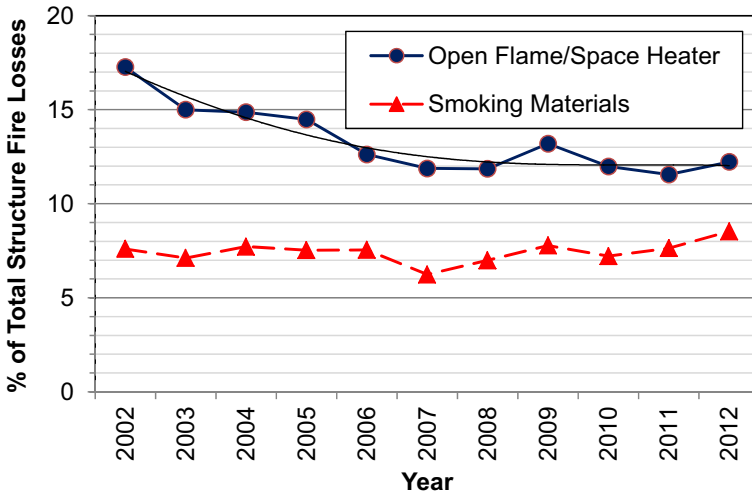


Note: Polynomial fits added to better visualize trends.



Note: Polynomial fits added to better visualize trends.

Figure 8. a Percentage of total 2002–2012 U.S. structure fires grouped by ignition source and hour of alarm. b Percentage of total 2002–2012 U.S. structure fire fatalities grouped by ignition source and hour of alarm. c Percentage of total 2002–2012 U.S. structure fire injuries grouped by ignition source and hour of alarm.



Note: Polynomial fit added to better visualize trend.

Figure 9. Proportions of total firefighter-reported U.S. property losses for 2002–2012 structure fires contributed by low-energy and smoking materials ignition sources.

the NFIRS database there is a distinction between unreported losses and zero loss fires, such that structure fires with reported losses are actually a subset of all structure fires. Figure 9 captures the relative contributions of low-energy and smoking materials ignition fires to the overall firefighter reported property plus contents losses for 2002–2012 structure fires. As one can see, reported losses from low-energy ignition sources contribute well more than smoking materials ignition losses, and it is apparent that the trends in fire losses reasonably mirror the actual fire trends from Figure 7a.

It can be helpful to compare the relative interactions between heat sources and items first ignited to get a sense of what sorts of items seem particularly predisposed to ignition from said sources. In this paper, fatalities are of primary interest, and thus Table 6 contains the top ten highest fatality identified items first ignited for low-energy and smoking materials ignition fires, accompanied by the number of fires and injuries. For brevity, the items first ignited are identified using their NFIRS codes, a reference for which is included in Table 5. As one can see, for both low-energy and smoking materials ignition, upholstered furniture and bedding fires are universally bad. Aside from this clear fact, it is worth noting that in terms of fatalities, both low-energy and smoking materials ignition sources contain the same sorts of item first ignited in the top ten, indicating that low-energy and smoking materials ignition appear to share the same sorts of problems.

8. Statistical Comparison of Low-Energy and Smoking Materials Ignition Fire Fatalities

A logistic regression model is a useful way to explore the statistical differences between low-energy and smoking materials ignition fires. Such a model has been successfully applied to comparisons of various aspects of the fire problem, and additionally to comparisons between states [26, 27]. Note that estimates outlined in this section are actually the average estimates of the 16 imputed datasets, as discussed earlier in this paper.

Table 7 provides motivation for the development of this model. One can qualitatively confirm that for upholstered furniture fire fatalities, the ignition source was highly likely to be smoking materials for individuals 21 years or older, but more likely to be low-energy ignition for individuals 21 years or younger. This question of which ignition source is more likely to have been involved in the fire that caused the fatality is what drives the development of the logistic regression model.

A logistic regression model traditionally takes the following form [28]:

$$E \left[\log \left(\frac{P(F|\vec{x})}{1 - P(F|\vec{x})} \right) \right] = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots + \beta_M x_M \quad (6)$$

The linear predictor, \vec{x} , contains the explanatory variables used in the model. $P(F|\vec{x})$ here describes the probability that a fire resulting in a fatality with given explanatory variables was started by low-energy ignition. The linear predictor for the initial model was formed thus:

$$\vec{x} = (\text{gender}, \text{race}, \text{area_orig}, \text{first_ign}, \text{rcs}_5(\text{age}), \text{rcs}_5(\text{hour}), \text{climate_reg}, \text{season}) \quad (7)$$

where the explanatory variables are defined as follows: gender = factor with 2 categories specifying gender of the victim (see Table 8 for a list of categories for each explanatory variable); race = factor with 2 categories specifying race of the victim; area_orig = factor with 4 levels specifying the area where the fire originated (e.g. bedroom); first_ign = item first ignited (e.g. upholstered sofa or chair); age = the age of the victim, specified non-linearly using a 5-knot restricted cubic

Table 7
Percentage of Upholstered Furniture Fatalities ($n \approx 1049$) in 2002–2012 U.S. Structure Fires for Which the Ignition Source Was Either Low-Energy or Smoking Materials

Age category	Smoking materials ignition	Low-energy ignition
Old (65 or older)	15.9	4.0
Middle-aged (21 to 64)	24.2	7.7
Young (21 or younger)	3.0	5.6

Table 8
Legend of Categorical Variables Codes Used in Simplified Logistic Model

Category	Code	Meaning
first_ign	0	Item first ignited not covered by proceeding levels
	20	Furniture, utensils, not covered by 21
	21	Upholstered sofa, chair
	30	Other soft goods and wearing apparel not covered by 32, 35
	32	Matress, bedding: pillow, blanket, sheet, comforter
	35	Wearing apparel on a person
race	65	Flammable liquid/gas, accelerants
	0	Non-white victim
	1	White victim

spline (referred to as *r_{cs5}*); hour = the hour of the day during which the fire resulting in the fatality took place, specified non-linearly using a 5-knot restricted cubic spline; climate_reg = factor with 9 levels indicating climate region of the United States as defined by the National Oceanic and Atmospheric Administration (NOAA); and season = specified according to the 3 month block definitions found in the U.S. National Weather Service (NWS) glossary.

This model was built using 16 sets of imputed observations each representing fatalities that occurred in a reported 2002–2012 structure fire whose ignition source was identified as either low-energy or smoking materials. Multiple imputation-modified Wald tests of significance, outlined in Van Buuren [29], for the predictors indicated that gender, area of origin, hour, and climate region were not statistically significant to the model. Thus, a second simplified model was built, the linear predictor of which was specified as follows:

$$\vec{x} = (r_{cs5}(age), first_ign, race, season) \tag{8}$$

To examine the goodness of fit of the simplified model, the c-index as described in [28] is used. The c-index is numerically identical to the area under the receiver operating curve of the model, and is in general a measure of model discrimination between the two outcomes of interest, i.e., whether a fatality came from a fire with a low-energy ignition source or a smoking material ignition source. To calculate it, one examines the model’s predictions for all possible pairs of fatalities where one fatality came from a smoking materials ignition fire and the other came from a low-energy ignition fire. The c-index is then the proportion of these pairs where the model ascribed a higher probability of low-energy ignition to the actual low-energy ignition fire fatality, compared against the probability of low-energy ignition ascribed to the smoking materials ignition fire fatality.

For this model, the c-index was calculated as the average of the c-indexes calculated from the 16 imputed datasets using the combined estimates model, which was 0.738. Harrell [28] states that a c-index above 0.8 indicates the model possesses some utility for predicting individual cases. From this rule of thumb one

can conclude that the model developed here is perhaps not so discriminating that its individual case predictions can be readily trusted, but that it is discriminating enough that one can trust the relative magnitudes of the explanatory variable effects calculated for the model.

A useful way to examine the impact of the explanatory variables in the model is to examine their respective odds ratios compared to baseline categories. To restate from [26] “Mathematically, the odds ratio can be represented as follows, using [race] and examining [ignition source] as an example

$$OR = \frac{\text{Odds}(\text{Fire fatality resulting from low - energy ignition} \mid \text{race} = 0, \vec{z})}{\text{Odds}(\text{Fire fatality resulting from low - energy ignition} \mid \text{race} = 1, \vec{z})} = e^{(\alpha + \beta_{\text{race}=0} - \alpha)} = e^{\beta_{\text{race}=0}} \tag{9}$$

which is the point estimate of the race category (0), as compared to the race category (1),” which in this model was a default case value, and was thus rolled into the intercept α . In the simplified model, the point estimate of $\beta_{\text{race}=0}$ was 0.594, resulting in an odds ratio point estimate of 1.81, as seen in Figure 10. The odds ratios of the categorical variables convey the ability of the model to distinguish various categorical levels from the default case, which for this model was `first_ign = 21` (upholstered furniture), `race = 1` (white), `season = winter`. Table 8 is a legend of values

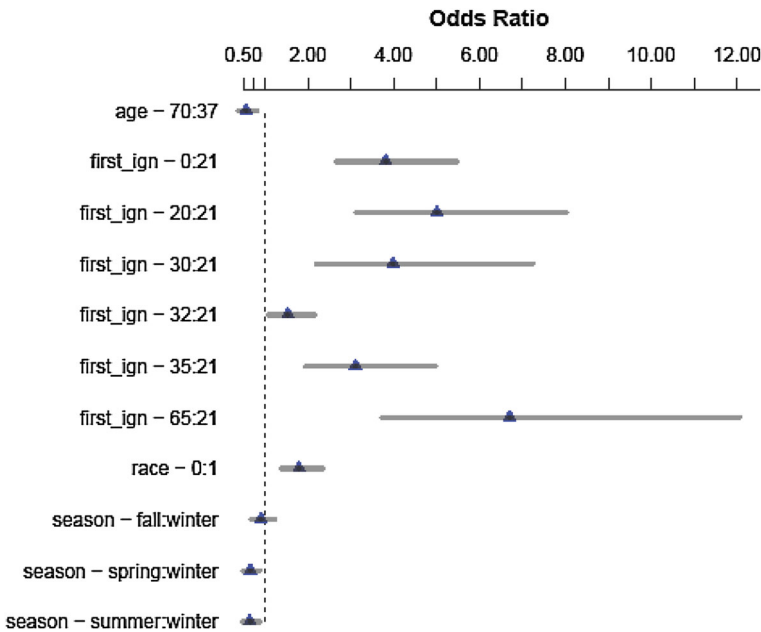


Figure 10. Predicted odds ratios and 95% intervals of variables to reference values. (Note codes on the right of each category indicate the reference values for the odds ratios).

outlining the meaning of the codes used in the categorical variables in Figure 10. Note that odds ratios below one indicate a multiplicatively lower odds of the fatality being involved in a fire ignited by a low-energy ignition source, while odds ratios above one indicate the opposite. The bars in Figure 10 represent 95% confidence intervals about predicted odds ratios. Predictors with intervals coinciding with the dashed line are not statistically significantly different from the base comparison cases.

Examining Figure 10, it is clear that the odds of a fire fatality being due to a fire caused by low-energy ignition instead of smoking materials ignition increases the younger a person is. Additionally, upholstered furniture (21) fire fatalities are more likely than any other item first ignited to be caused by smoking materials ignition. White people are also at increased risk to become fatalities in a smoking materials caused fire, compared against all other races. Finally, the winter time is associated with the highest probability of low-energy ignition fatalities, likely due to the increase use of space heaters during that season.

It is worthwhile, in addition to Figure 10, to display the dependence of the log odds on the continuous explanatory age variable. Figure 11 displays the variation in the log-odds over various ages for a white fatality for whom the first item ignited was upholstered furniture, during the winter time. Because the model included no interaction terms, the functional dependency outlined in Figure 11 is consistent across the categorical levels of race of victim, item first ignited, and season. Examining Figure 11, which to remind the reader, was a non-linear 5 knot restricted cubic spline specification on age, one can see an almost parabolic shape, with the highest log odds of the victim being killed by a fire caused by low-energy ignition instead of smoking materials occurring at younger ages, reaching a minimum at roughly 74, and then rising again as age increases beyond 74.

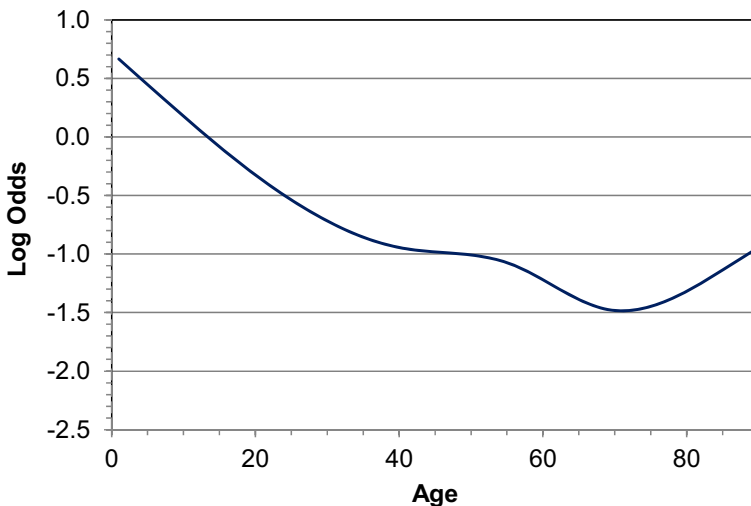


Figure 11. Functional dependence of logistic regression model linear predictor (the log odds) on age.

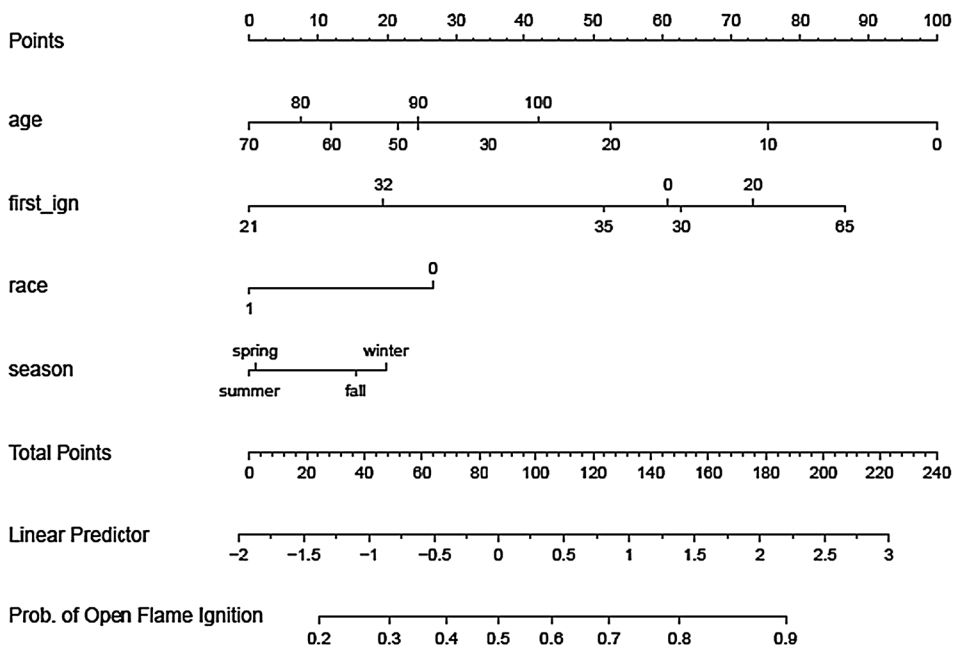


Figure 12. Nomogram of model, visualizing the relative strength of the predictors while also allowing practical examination of model predictions (linear predictor values are on the log odds scale).

Finally, Figure 12 depicts a nomogram of the simplified model. A nomogram is a graph designed to enable manual model predictions by summing the individual points contributions of various explanatory variables (denoted on the graph as “points”), and then summing all these individual points contributions along the “total points” bar. Beneath these total points is the value of the linear predictor based on those point estimates, along with the inverse logit of the linear predictor, which is the model’s predicted probability that a given fatality was involved in a fire caused by low-energy ignition as opposed to smoking materials ignition.

For example, assume a case where there is a 20 year old white fatality in a fire where the item first ignited was bedding during the summer. From the nomogram, one can approximately tally up the individual points, 50 for age = 20, 20 for first_ign = 32, 0 for race = 1, and 0 points for season = summer. This calculation results in a total of 70 points, which, examining the “total points” bar on Figure 12 and then moving straight down to the “Prob. of low-energy ignition” bar, corresponds to a probability that the ignition source for the fire resulting in this particular fatality was roughly 0.42.

Practically however, for the purposes of this paper, Figure 12 is perhaps more useful for visualizing to the reader both the extent to which the individual explanatory variables contribute to the model (larger bars mean a stronger contribution), as well as how individual values or categories within these variables affect model prediction. It is clearly apparent that age is the strongest predictor of igni-

tion source, followed by the first item ignited, the race of the victim, and finally the season during which the fire occurred. In addition, one can see, for example, that there is a fairly clear separation between upholstered furniture, mattress, and bedding fires, which are strongly associated with smoking materials, and other forms of item first ignited, which instead possess more correlation with low-energy ignition fires.

9. Conclusions

This paper has substantively examined the issue of low-energy ignition sources versus smoking materials ignition sources in several contexts. First, a qualitative international comparison was made between the U.S., the U.K., Japan, and Finland. From this comparison it can be concluded that, compared to the other nations the U.K. appears to have more of a problem with smoking materials ignition fires resulting in fatalities, but otherwise closely resembles the U.S. in terms of fire problems contributed by low-energy and smoking materials ignition sources. Additionally, Japan appears to have appreciably more smoking materials ignition fires, and up to a lesser extent low-energy ignition fires, than the other nations. It is also worth noting that the sorts of items first ignited associated with smoking materials and low-energy ignition fires differ along cultural boundaries between Japan versus the U.S. and the U.K. Finally, the impact of the introduction of RIP cigarettes in the U.S., and more recently in Finland and the U.K., on the number of fatalities in smoking materials ignition fires is not evident from the statistics.

Second, summary graphs created using U.S. NFIRS database data were examined, and display the general differences between fires, fatalities, injuries, and losses for low-energy ignition versus smoking materials ignition fires, for yearly and hourly trends. From these graphs, it is apparent that smoking materials ignition fires tend to more commonly result in fatalities than low-energy ignition fires, while the overall volume of low-energy ignition fires is greater. This greater volume of fires also appears to contribute to the larger percentage of injuries observed in low-energy ignition fires compared against smoking materials fires.

Finally, a statistical comparison was performed between fatalities involved in fires associated with low-energy ignition versus smoking materials ignition. From this comparison, it can be concluded that age, item first ignited, race, and season of year are all significant variables in differentiating between low-energy ignition fire fatalities and smoking materials fire fatalities. Notably, the older a person is, generally the more susceptible they are to perishing in a fire resulting from smoking materials ignition rather than low-energy ignition. Also notable is that upholstered furniture, mattress, and bedding fires tend to be strongly correlated with smoking materials ignition sources, with regards to fatalities compared against other potential first items ignited.

The apparent insignificant impact of the introduction of RIP cigarettes on the relative contribution of fire fatalities from smoking materials fires to the U.S. fire problem warrants further investigation. New York was the first state to enact RIP

cigarette legislation (December 31, 2003; implemented June 28, 2004). Wyoming was the last state to enact RIP cigarette legislation (March 8, 2010; implemented July 1, 2011). The latest NFPA report on smoking-related fires [24] deaths due to cigarette-ignited fires 2011 are down by 30% from 2003, the latest year before any state implemented an RIP cigarette law. The report further states “It seems clear that the change in the cigarette has been the principal driver in the 30% decline in smoking-material fire deaths.” However, the number of U.S. deaths aggregated over all ignition sources has also decreased by 30% in the 2003–2011 period [30]. Additionally, Figure 7b shows no sign that smoking materials fatalities have declined faster than the overall fatality rate over the period 2003–2011, which might be expected if fire safe cigarettes are a principal driver of the decline in smoking materials fatalities. Regardless, future monitoring of smoking material fire deaths in the U.S. and the E.U. (Finland was the first E.U. country to require RIP cigarettes in 2010, and the entire E.U. followed suit in 2011) may provide a more reliable estimate of the true impact of RIP cigarettes.

Acknowledgments

The authors greatly acknowledge the financial support of the American Chemistry Council for the work described in this paper. The authors also want to express their gratitude to Mr. Nazneen Chowdhury, Dr. Tuula Hakkarainen, and Dr. Ai Sekizawa for providing the statistical data for this study from the U.K., Finland, and Japan, respectively. The authors also appreciate the critique provided on an earlier version of this manuscript by anonymous reviewers.

References

1. U.S. Fire Administration (2012) National fire incident reporting system (NFIRS). U.S. Fire Administration, Emmitsburg, MD
2. Office of the Deputy Prime Minister (2006) Fire statistics, United Kingdom, 2004. Office of the Deputy Prime Minister, London, UK
3. Department for Communities and Local Government (2008) Fire Statistics United Kingdom, 2006. Department for Communities and Local Government, London, UK
4. Department for Communities and Local Government (2009) Fire Statistics United Kingdom, 2007. Department for Communities and Local Government, London, UK
5. Department for Communities and Local Government (2010) Fire Statistics United Kingdom, 2008. Department for Communities and Local Government, London, UK
6. Department for Communities and Local Government (2011) Fire Statistics Great Britain, 2010–2011. Department for Communities and Local Government, London, UK
7. Department for Communities and Local Government (2012) Fire Statistics Great Britain, 2011–2012. Department for Communities and Local Government, London, UK
8. Department for Communities and Local Government (2014) Fire Statistics: Great Britain April 2012 to March 2013. Department for Communities and Local Government, London, UK

9. Department for Communities and Local Government (2012) Incident recording system—questions and lists. Department for Communities and Local Government, London, UK
10. The Geneva Association (2014) World fire statistics bulletin no. 29. The Geneva Association, Geneva
11. Hocken R (2012) Comparison of European fire statistics final report for the department for communities and local government. Department for Communities and Local Government, London
12. Sekizawa A (1994) International comparison analysis on fire risk among the United States, The United Kingdom, and Japan. In: Fire safety science—proceedings of the fourth international symposium. International Association of Fire Safety Science, London, pp 195–204
13. Hall J (2003) Fire in the U.S. and Japan. National Fire Protection Association, Quincy, MA
14. Hall J (2005) Fire in the U.S. and the United Kingdom. National Fire Protection Association, Quincy, MA
15. Hall J (2004) Fire in the U.S. and Sweden. National Fire Protection Association, Quincy, MA
16. U.S. Fire Administration (2011) Fire death rate trends: an international perspective. Topical fire report series, vol 12, no 8. U.S. Fire Administration, Emmitsburg, MD
17. Hall J, Harwood B (1989) The national estimates approach to U.S. fire statistics. Fire Technol 25(2):99–113
18. Miller D (2013) 2009–2011 residential fire loss estimates. U.S. Consumer Product Safety Commission
19. Honaker J, King G (2010) What to do about missing values in time series cross-section data. Am J Polit Sci 54(2):561–581
20. Rubin DB (1987) Multiple imputation for nonresponse in surveys. Wiley, New York
21. Sekizawa A (1991) Statistical analyses on fatalities characteristics of residential fires. In: Fire safety science—proceedings of the third international symposium. International Association of Fire Safety Science, London, pp 475–484
22. Sekizawa A (2013) Challenges in fire safety in a society facing a rapidly aging population. In: 2013 SFPE annual meeting. Society for Fire Protection Engineers, Gaithersburg, MD
23. OECD Health Data: Non-medical determinants of health. http://www.oecd-ilibrary.org/social-issues-migration-health/data/oecd-health-statistics/oecd-health-data-non-medical-determinants-of-health_data-00546-en
24. Hall J (2013) The smoking-material fire problem. National Fire Protection Association, Quincy, MA
25. (2011) National fire incident reporting system version 5.0 fire data analysis guidelines and issues. U.S. Fire Administration, Emmitsburg, MD
26. Anderson A, Ezekoye O (2013) A comparative study assessing factors that influence home fire casualties and fatalities using state fire incident data. J Fire Prot Eng 23(1):51–75
27. Hasofer A, Thomas I (2006) Analysis of fatalities and injuries in building fire statistics. Fire Saf J 41(1):2–14
28. Harrell F (2001) Regression modeling strategies: with applications to linear models, logistic regression, and survival analysis. Springer, Berlin
29. van Buuren S (2012) Flexible imputation of missing data. CRC Press, Boca Raton, FL
30. Haynes H (2014) Fire loss in the United States during 2014. National Fire Protection Association, Quincy, MA