# Estimating Fires When a Product is the Primary Fuel But Not the First Fuel, With an Application to Upholstered Furniture

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## Abstract

Since 1980, it has been possible to estimate the size of the fire problem associated with many types of burnable products when those products are the first items ignited. However, many burnable products also have a major role as the largest fuel package in the room and may be the most important fuel package even if not the first item ignited. Only in the last few years have we had enough years of fire data with coding sufficient to support sound estimates of fires where a defined product is the primary fuel but not the first fuel. This article describes a proposed methodology for making those estimates and describes the results of application of the new methodology to upholstered furniture. The application to upholstered furniture demonstrated that one-quarter of upholstered furniture fires, civilian injuries, and direct damages, and one-fifth (21%) of associated civilian deaths are associated with fires in which upholstered furniture is the primary item contributing to fire or flame spread but not the item first ignited. The traditional focus on cigarette resistance leaves roughly half of the fire deaths from upholstered furniture fires untouched.


## Introduction

In addition to support for estimates of the size, characteristics, and trends in the national fire problem, national fire incident data and statistics can be highly useful in analyzing the likely impact of alternative strategies and choices. This includes alternative choices for the design of products, including products that serve as fuel for the fire, either initially or at some point during the growth and spread of the fire (where the products range from contents like mattresses, bedding, and upholstered furniture, to installed furnishings like cabinets and wall linings, to parts of the building, like thermal insulation).

Since 1980, U.S. national fire incident statistics have been developed using standard analysis rules applied to detailed data from the National Fire Incident Reporting System (NFIRS), which is administered by the U.S. Fire Administration (part of the Federal Emergency Management Agency, within the U.S. Department of Homeland Security). NFIRS collects standardized fire incident and casualty reports from participating fire departments. States set the NFIRS participation requirements for their jurisdictions and perform varying amounts of quality control and training.

NFIRS is a large database, containing a large fraction of all the U.S. fires reported to municipal fire departments. It is not complete enough to be treated as a census, and it is not a random sample, where the statistical rules for projecting from samples are well defined. There are systematic biases in participation by departments, which may reflect differences in state requirements (is participation mandatory or voluntary?) or differences in resources required to maintain full participation. There are systematic biases in the likelihood that a fire will be included, which may reflect differences in thresholds of fire

severity for mandatory reporting. At the same time, NFIRS includes such a large share of total U.S. fires (reported to fire departments) that it can be treated as having some or much of the representativeness found in a true random sample, certainly more than is found in other fire incident databases not designed as random samples.

Also, unknown percentages are large for some data elements (as will be illustrated for specific data elements later in this article), and this problem is greater for some fires and some data elements. For example, some data elements are not mandatory for some fires. Unless some compensation is made for missing fires and this missing data, fire statistics will seriously under-estimate the fire problem.

In the early 1980s, NFIRS users at the U.S. Fire Administration (USFA), the Consumer Product Safety Commission (CPSC), and the National Fire Protection Association (NFPA) experimented with variations of standard rules for developing NFIRS-based national estimates in a consistent and defensible manner. By the end of the decade, there was broad agreement among national analysts of NFIRS data on the principles to be used in making projections. (Hall and Harwood, 1989)

The standard method compensates for missing fire departments by using a stratified random-sample based survey – the NFPA annual fire experience survey – to estimate the annual totals for fires and losses, and then treats the NFIRS dataset as a sample from those totals, using scaling ratios based on the NFPA-survey-based totals divided by the corresponding NFIRS totals. Other methods use other sources for totals – such as the U.S. death certificate data base – but these other databases typically have important differences in the definition of an eligible fire or fire loss. For example, death certificates are not limited to deaths in fires reported to fire departments and may not include homicides, suicides and vehicle fire deaths. Insurance fire loss databases may not include uninsured fire losses or deductibles and may include losses in fires not reported to fire departments.

The standard method compensates for missing data by proportionally allocating unknowns for any data element over the knowns, thereby assuming that the unknowns are most likely to resemble the knowns.

The specifics have changed because some data elements have changed, but the general approach, with some added specifications, applies equally well to the new data elements and other changes in successive versions of NFIRS, including the current version 5.0.

**Estimating the Fires Associated with a Burnable Product**

When the specific concern is with a product's role as the first item ignited, it is natural to talk about the goal of prevention. A fire may be stopped before it begins if the initial fuel is changed. There are standard fire tests for ease of ignition of particular products when exposed to certain heat sources (such as a test for ease of ignition of upholstered furniture by a cigarette or other smoldering heat source). There are code requirements and other regulations that block products from entering the marketplace if they do not pass such tests.

When the specific concern is with a product's role as the primary fuel but not the first fuel, the implied fire scenario involves ignition of the product by another unwanted fire, which can be safely assumed to be a stronger ignition heat source, larger and more intense, than a smoldering cigarette or small open flame. In such cases, complete prevention may be an unattainable goal, but if such a product can be reengineered so that it burns with a slower rate of growth and/or a lower, less intense peak, then there should be fewer large fires and potentially substantial reductions in fire loss.

Of course, before spending the resources required to pursue this kind of loss mitigation through product redesign, there should be evidence that the loss reduction will be worth the cost. The benefits from a design change will be some fraction of the losses associated with the current design. Therefore, the first quantities needed for policy analysis are best estimates of the fire losses associated with a particular product of interest when that product's role is that of principal secondary fuel package, not initial fuel package. That is the estimation problem that this article seeks to address.

## Changes in NFIRS That Made the Desired Type of Estimation Possible

In 1999, version 5.0 of NFIRS introduced a data element labeled *item contributing most to flame spread*. The coding choices for this new data element are identical to the coding choices for the long-time data element labeled *item first ignited*. This means estimates can be developed for the same product groups for fires involving the product in either role, as first fuel or as the most important secondary fuel.

Prior to 1999, NFIRS data elements on contributors to fire spread were either

a) not designed to distinguish types of products (for example, based on the material composition of the product not its function),
b) structured in terms of a long list of candidate factors, including many factors that were not burnable products (which means that many fires with this data element coded would not have been evaluated in terms of principal item contributing to fire spread), or
c) focused on other fire performance characteristics than fire or flame spread (for example, *item generating most smoke*, a data element used during some of the versions of NFIRS).

The new data element saw relatively little use in the first several years after the introduction of NFIRS version 5.0. Analysis of this data element involves some technical complications that cannot be addressed by simple extensions of the standard method for analyzing NFIRS data. One complication is the need to isolate all and only those fires with enough fire/flame spread that it is meaningful to ask which item was the primary contributor to that spread. Another complication is the need to avoid double-counting fires where the product was both the first item ignited and the primary contributor to fire/flame spread.

A third complication is the variation in descriptions of fire spread in two important data elements. The data element that identified the "item contributing most to flame spread"

refers to "*flame* spread" while the data element describing the size of the fire refers to "*fire* spread." In order to use these two data elements together in an analysis, it is necessary to assume that these two terms are being used in the field to describe the same kind of spread. It is possible that the term "flame spread" may provide a subtle push toward surfaces (room linings) that flame may spread along rather than major fuel packages that will support fire growth leading to fire spread. This may tend to understate the contributions of major fuel packages like upholstered furniture and overstate the contributions of room linings like ceiling and wall coverings.

## Events That Led to the Development of This Analytic Approach

In order to make it worthwhile to work through the technical complications, there needed to be a particular product type that was (a) known to account for a major share of the fire problem, (b) credibly suspected to also have a major role as a secondary major fuel, and (c) in the spotlight because of heightened national interest in new strategies for fire-safe design of the product or new information on the safety of old strategies. The two products that fit those descriptions best in recent years were mattresses (grouped with bedding) and upholstered furniture. For one thing, they are the products that have long ranked second and first in number of civilian deaths in home fires when ranked by product as item first ignited.

During the 2000s, test standards for mattresses were overhauled, but those discussions did not pursue quantification of the secondary fuel part of that fire problem. In part, this might have been because the U.S. was still converting to version 5.0 of NFIRS during the early part of this period, when the problem was framed, and the potential power of the new data element may not have been widely recognized.

The situation was different for upholstered furniture. A 2012 National Institute for Standards and Technology workshop on flaming residential upholstered furniture identified a need to fill out existing estimates of the upholstered furniture fire problem with estimates of fires where upholstered furniture's role was that of the principal fuel package, not the first fuel package.

This article describes the methodology developed in response to that identified need and includes the results obtained when it was applied to upholstered furniture. The methodology can be applied to any product, and the author has begun using the method to develop more complete summaries of the total fire problem associated with various product classes, in support of periodic advocacy prioritization exercises and as input to the design of broadly effective fire risk reduction strategies for the whole fire problem associated with a target product class.

## Estimating the Number of Fires with a Defined Item as Primary Contributor to Fire/ Flame Spread

### The Special Problem of Blanks

As suggested by the earlier description of unique technical complications, the development of this new analysis method primarily involved questions about how best to handle fires with missing data. More specifically, the central question was how best to handle fires where item contributing most to fire/flame spread was left blank. Under NFIRS rules, a blank can be recorded for any or all of four reasons. The first two of these reasons can be addressed fairly straightforwardly:

*(1) There was no "significant" fire/flame spread* or *(2) it was not possible to determine whether there was fire/flame spread.* In keeping with the general principles of the established standard method, fires with unknown fire size can be proportionally allocated across the known fire sizes. Analysis can then be conducted on only those fire sizes that constitute "significant" fire/flame spread.

Some fire sizes clearly involve "significant" fire/flame spread (for example, not confined to floor of origin). Some fire sizes clearly do not (for example, fires confined to object of origin). Therefore, the analytical question is how to treat fire sizes in between these two extremes.

If the use of blanks for these intermediate-size fires closely resembles the use of blanks for one or the other of the two extremes of fire sizes, then there is an empirical basis for including or excluding these intermediate-size fires in the group of fires with "significant" fire/flame spread, based on the approach taken with the more extreme fire sizes that they resemble.

Using 2006-2010 NFIRS fire data for home fires (where home includes all housing units, including multi-family and manufactured home), the percentages blank and unknown are as follows, by extent of fire spread:

- Confined fires[1] – 100% blank; 0% undetermined
- Confined to object of origin – 95% blank; 1% undetermined
- Beyond object but confined to room of origin – 62% blank; 4% undetermined
- Beyond room but confined to floor of origin – 59% blank; 7% undetermined
- Beyond floor but confined to building of origin – 63% blank; 9% undetermined
- Beyond building of origin – 62% blank; 11% undetermined

The last two groups (everything with fire spread at least beyond floor of origin) should be considered large enough to satisfy any definition of "significant" fire/flame spread. The first two groups (both confined to object of origin) just as clearly should not involve

[1] NFIRS Version 5.0 identified a new category of "confined fires" – confined to cooking vessel, chimney or flue, fuel burner or boiler, incinerator, compactor, or trash – and allows much less detailed reporting for such fires. In terms of fire size, these fires should all be confined to object of origin.

"significant" fire/flame spread under any definition. In terms of percentage blanks, the middle two groups clearly resemble the last two groups closely and much more than they resemble the first two groups. Therefore, analysis should focus on the last four groups as all representing significant fire/flame spread. Any blanks reported for these fires should be assumed to involve one of the other two reasons allowed under NFIRS:

*(3) The item contributing most to flame spread was the same as the item first ignited* or *(4) the type of item contributing most to flame spread was unknown*. If the reason is #3, we want to identify those fires and separate them to avoid double-counting. If the reason is #4, we want to proportionally allocate those fires over the known items.

There is no direct way to check which of these situations applies, but it is possible to look at related statistical data. NFIRS uses the same list of items for recording of item first ignited and primary item contributing to fire/flame spread. Some of these items would not be expected to be present in sufficient quantity to contribute to fire/flame spread. Some other items are recognized as classic primary avenues of fire/flame spread or growth.

The two extreme forms of analysis are to assume that all blanks signify the same item as the item first ignited or that none of the blanks so signify. If all blanks signify item first ignited, then all blanks can be assigned values based on the item first ignited. If no blanks signify item first ignited, then all blanks can be treated as unknowns on primary item contributing to fire/flame spread and proportionally allocated over the knowns. In either case, it is possible to develop a distribution of items as primary items contributing to fire/ flame spread, as shown in Table 1.

**Table 1. Selected Items as Primary Item Contributing to Fire/Flame Spread, Percent Shares of 2007-2011 Non-Confined Home Structure Fires, by Two Different Analysis Methods**

| Primary item contributing to fire/ flame spread | If all blanks are treated as unknowns | If no blanks are treated as unknowns |
|---|---|---|
| Structural member or framing | 17.9% | 12.1% |
| Unclassified structural component | 8.2% | 5.0% |
| Exterior wall covering | 7.6% | 7.1% |
| Cooking materials | 7.3% | 9.1% |
| Interior wall covering | 5.9% | 4.4% |
| Cabinetry | 5.9% | 3.3% |
| Mattress or bedding | 5.0% | 4.6% |
| Upholstered furniture | 4.0% | 3.2% |
| Unclassified furniture or utensil | 3.3% | 2.8% |
| Clothing | 2.8% | 3.4% |
| Wire or cable insulation | 1.8% | 6.7% |

Source: NFPA analysis of data reported to NFIRS and the NFPA survey.

The items with higher percentages in the right column – cooking materials, clothing, wire or cable insulation – are all items with insufficient mass to form a basis for fire/flame spread in most instances. The items with the higher percentages in the left column,

especially the items with the largest differences relative to the right column – structural member or framing, unclassified structural component, cabinetry, interior wall covering – are all items that are natural candidates as paths for fire/flame spread. This suggests – but does not conclusively demonstrate – that the more plausible analytical approach is to treat blanks as unknowns.

**Overview of the Statistical Method**

Here are the final steps in the statistical method, incorporating the decisions made above regarding the handling of unknowns and blanks when analyzing the number of fires involving an "item of interest" as the primary item contributing to fire/flame spread.

1) Develop estimates of fires and losses for each of the six fire sizes, including proportional allocation of fires with extent of fire/flame unknown or blank.

2) For each of the four fire size groups involving fire/flame spread beyond the object of origin, estimate the number of fires and associated losses with the item of interest coded as the primary item contributing to fire spread, including proportional allocation of unknown or blank entries for primary item contributing to fire spread.

3) To avoid double-counting, for each fire size, estimate the number of fires and associated losses with the item of interest coded as both item first ignited and primary item contributing to fire/flame spread, then remove these fires and losses from the final estimate of fires with item as primary item contributing to fire/flame spread.

   There is a discretionary step involving the two smallest fire sizes, wherein fires are included if they are reported as involving the item of interest as primary item contributing to fire/flame spread, but there is no allocation of blanks and unknowns, which as noted earlier account for nearly all these fires. In the application to upholstered furniture, the two smaller fire sizes were included, which changed the estimates by at most 1%.

4) Sum the estimates from step 3, and the result is the desired combined estimate.

**Application to Upholstered Furniture**

As noted earlier, this new statistical method was developed to support more complete estimates of the fire problem associated with upholstered furniture. This section describes the results of applying the method to the upholstered furniture fire problem, and the associated implications for the overall size of that fire problem.

First, the method described in the previous section must be applied to NFIRS data on reported upholstered furniture home structure fires. This analysis used 2006-2010 data because that was the latest data available at the time. Table 2 summarizes the results of this

exercise and the estimates of reported fires and associated losses for upholstered furniture as primary item contributing to fire/flame spread.

**Table 2. Fires With Upholstered Furniture as Primary Contributor to Fire or Flame Spread But NOT as Item First Ignited**

| Fire spread | Fires | Civilian Deaths | Civilian Injuries | Direct Damage (in Millions) |
|---|---|---|---|---|
| Confined fire | 6 | 0 | 1 | US$0 |
| Confined to object of origin | 11 | 0 | 2 | US$0 |
| Confined to room of origin | 944 | 41 | 101 | US$28 |
| Confined to floor of origin | 369 | 17 | 41 | US$23 |
| Confined to building of origin | 808 | 64 | 109 | US$74 |
| Beyond building of origin | 85 | 8 | 21 | US$14 |
| Total | 2,223 | 130 | 276 | US$138 |

Source: NFPA analysis of data reported to NFIRS and the NFPA survey.

To provide some context, these fires represent a one-third addition to the fires, injuries and damages associated with fires beginning with ignition of upholstered furniture, as well as a one-quarter addition to the deaths.

The next step was to add these results to a statistical overview of the upholstered furniture fire problem, subdivided by major scenario. Most analyses of upholstered furniture fires and losses and most standard tests and regulations have treated the fire problem as involving two scenarios: (1) smoldering ignitions, typically by cigarettes or other smoking materials, and (2) small open flame ignitions, typically by lighting implements such as matches or lighters, with some recognition of ignitions by candles and ignition by persons intentionally starting a fire or by children playing with fire.

As part of the recent analysis of the major parts of the fire problem, two other scenarios defined by circumstances of ignition were identified: (3) ignition by operating equipment, where it is not clear whether the mode of heat transfer resembles smoldering ignition by a cigarette or open flame ignition by a small heat source, and (4) ignition by ember, ash, or other or unclassified hot or smoldering object, where again it is not clear whether the ignition process is well represented by the two traditional scenarios.

Table 3 provides an overview of the upholstered furniture fire problem, including the four ignition scenarios, the scenario of upholstered furniture as primary item contributing to fire spread but not item first ignited, and a sixth scenario for fires with no details on manner of ignition. Civilian deaths are highlighted and used to rank the six scenarios, because civilian deaths are by far the most important type of loss in discussions about fire risk and the need to reduce risks for particular products.

**Table 3. Upholstered furniture fire problem, 2006-2010 averages, including fires with upholstered furniture as primary item contributing to fire spread, by major scenario**

| | Fires | Civilian Deaths | Civilian Injuries | Direct Damage (in Millions) |
|---|---|---|---|---|
| Lighted tobacco product | 1,900 (21%) | **270 (45%)** | 320 (29%) | US$97 (17%) |
| Open flame from other fire | 2,200 (25%) | **130 (21%)** | 280 (25%) | US$138 (24%) |
| Operating equipment | 1,500 (17%) | **70 (12%)** | 140 (13%) | US$81 (14%) |
| Small open flame | 1,400 (16%) | **60 (10%)** | 220 (20%) | US$69 (12%) |
| Ember, ash or other or unclassified hot or smoldering object | 1,300 (15%) | **60 (10%)** | 130 (11%) | US$150 (27%) |
| Unclassified, other or multiple heat source | 600 (7%) | **20 (3%)** | 30 (3%) | US$31 (5%) |
| Total | 8,900 (100%) | **610 (100%)** | 1,120 (100%) | US$566 (100%) |

Source: NFPA analysis of data reported to NFIRS and the NFPA survey.

## Conclusions

An analysis protocol has been developed, based on extension of established NFIRS national estimates procedures to the data element of item contributing most to fire spread. This protocol offers the opportunity to provide a more complete estimate of fires associated with products that are burnable items.

The new protocol has been applied to the case of upholstered furniture. It has also been applied to some unpublished estimates of fires involving other large fuel packages (e.g., mattresses and bedding), products that serve as avenues of fire spread (e.g., ceiling, wall or floor coverings), and concealed combustibles, which may be difficult or unlikely to ignite until fire from another burning item reaches them through the walls or other barriers that surround them (e.g., thermal insulation, structural elements). All such analyses have been

conducted in the context of prioritizing fire problems for attention by fire safety professionals, especially by strategic advocacy campaigns, and designing strategies to target the largest parts of targeted fire problems.

The implications of the application of this analysis to upholstered furniture should be clear. Strategies that would address the upholstered furniture fire problem solely by increasing resistance to ignition by lighted tobacco products can be seen to target only one-fifth of the fires and less than half of the fire deaths.

Fires involving fire spread to upholstered furniture from other items – the fires that were estimated using the procedure described in this article – represent the second leading fire scenario for fire deaths. Strategies to address such fires would need to test resistance to ignition by a much stronger heat source (representing another burning item) than the test fire used when evaluating resistance to ignition by small open flame. In fact, such strategies might need to abandon the goal of prevention through resistance to ignition in favor of a goal of mitigation through improved fire performance (e.g., slower fire growth, lower peak intensities).

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