FIRE RESEARCH NEEDS

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PREFACE

This Paper was presented to the first annual conference of fire researchers sponsored by the National Fire Protection and Control Administration, U.S. Department of Commerce, on July 16, 1976 at the Applied Physics Laboratory, The Johns Hopkins University.

Research on fires and methods of fire protection may greatly reduce the cost of fire to society. This Paper presents an evaluation of selected research topics concerned with fire. Deaths and property destruction caused by fire have also been examined to help identify the important parts of the fire problem. That provides one basis for evaluating fire research topics; bigger problems deserve more attention. Some economic analyses of fire protection were also reviewed. They provide accounting frameworks and methods of measurement to assess the costs and benefits of alternative fire-protection strategies. Some of the most promising research topics in fire arise from economic issues addressed by those analyses.

The results reported here draw on a restricted set of research topics. I hope to draw attention to some relatively new and promising areas of fire research. Much valuable work in physical and biological sciences has been performed in recent years. Development of practical firefighting hardware and research on fundamental physical phenomena have advanced protection against fire in several areas. However, the topics examined here have not received as much attention. They include the behavior of firms selling fire insurance, the costs and benefits of detector-alarm systems, the consolidation of municipal fire departments and several others. All have been examined previously, but hard, comprehensive evidence of their impact on fire problems is, in most cases, yet to be obtained.

This analysis does not prove conclusively that any one research topic will produce more impact on fire than another. Too many stages separate an idea for research from its final impact on the fire problem. I sought to make plausible arguments that some projects offer major benefits. The first question in evaluating a prospective piece of research asks if the problem attacked is important. Next, one can ask if the research will yield results that can be generalized beyond the experiment or data base from which they are drawn. This might be answered by examining the theory, if any, which the research utilized or the homogeneity of settings in which real fires occur compared to the conditions examined by a specific research project. Finally, justification for public support of research depends on the degree to which the research product is a "public" good. If the benefits of the research fall indivisibly on the public, the potential difficulty of charging the beneficiaries may discourage potential investors from supporting the work. That quality of public goods usually inheres in research because it is so far removed from its ultimate impact and beneficiaries. But some topics of fire research will more likely produce marketable products from which private firms may earn profit than others.

Public funding of any topic of fire research should require, at a minimum, fulfillment of the three criteria mentioned below.

- The phenomonon addressed should be a major component of the fire problem.
- The research design should produce results that can be generalized to the environment of uncontrolled, destructive fires.
- The research product should be a public good in the sense that its benefits will tend to fall indivisibly on the public. Research having this characteristic is unlikely to arise spontaneously from free enterprise and thus may qualify for public support.

The first task of the project was to assess mortality by fire and other causes of death and to compare federal research expenditures directed at causes of death. Estimated federal research expenditures directed against major causes of death ranged from about $9 million in 1972 for fire to $490 million for research related to cancer and malignancies, about a 5 to 1 change from the largest to smallest. These estimates were then weighted by person years of life lost. This was done by use of life tables computed from mortality statistics. Knowledge of the number deaths by age and the remaining life expectancy by age is sufficient to compute the years of life lost per death, total years of life lost by cause, and research expenditures by per year of life lost. The range of research dollars spent per year of life lost is, very approximately, from $20 (cardiovascular-related deaths), to $150 (motor-vehicle-related deaths). Fire-related deaths received approximately $32 per year of life lost. Research expenditures could have been weighted by the simple number of deaths rather than number of person years of life lost. You will have to judge the appropriateness of the alternative measures. The use of person years of life experience lost captures one aspect of the difference between death after a full lifetime and death at a younger age. This measure also provides legislators with a broader picture of the distribution of public funds against hazards to life. Such data cannot prove the proper allocation of funds because that allocation is primarily determined by subjective assessments of the public interest. However, that normative problem can be simplified by knowledge of the consequences of the rather large number of governmental decisions concerning research expenditures.

A relatively new branch of research into fire problems are economic analyses. Economics is concerned with efficiency--defined either as the least cost way of achieving a given end, or the maximum value that can be attained from a given endowment of resources. This special focus of the discipline, and the quantitative tools which have been developed, means that economics can offer some insights into the problems associated with fire.

Fire exacts three costs from society: (1) The costs of preventing ignition, including the costs of meeting and enforcing building codes, public education, and other precautions; (2) The costs of extinguishing a fire after it has started; and (3) The costs of the damage done by fire. At present all three costs are large. Complicated tradeoffs exist between these categories. For example, costs could be reduced by spending less on extinguishing services, but by how much would the damage done by fires increase? The fire problem can be seen as the problem of minimizing the sum of these three cost components. Economic techniques are used to monitor the efficiency of the activities within and between each category.

Viewed in these terms, the economics of fire protection, particularly fire extinguishing services, can be broken down into two main aspects. Do the suppliers of services provide them efficiently, and do the users of the services behave efficiently? Because of the way in which fire suppression is supplied--usually through municipal fire departments, and the way in which users must pay--usually through local taxes, and the inadequate data upon which decisions are made, we argue that neither suppliers nor users are behaving efficiently. Changes are necessary in the way in which fire protection services are produced and utilized in order to improve economic efficiency. Research is needed in order to structure these changes effectively.

Why are fire suppression services publicly supplied? Economic theory suggests that private supply will be more efficient than public supply of most goods. Perhaps the most convincing explanation for the public provision of services lies within the desire of the public that fire protection should be available to everyone, regardless of ability to pay. However, this is only an argument for payment for the service through the public fisc, rather than complete public provision.

The consequences of public fire protection are difficult to quantify, but certain general conclusions can be drawn. First, the fragmented nature of local government has hindered the creation of efficient, fire protection areas in which such economies of scale as exist could be enjoyed. Second, the development and adoption of new fire fighting techniques and equipment are retarded by the fragmented nature of the "buyer's" market. Third, fire departments do not face "profit-loss" incentives to make the maximum use of resources at their disposal. As Ridley and Simon stated in 1943, "It is a poor administrator, indeed, who is not sufficiently enthusiastic about the service he is providing or sufficiently aware of its value to the community to see opportunity for expanded service." Lastly, users of fire protection services do not face the proper incentives to take appropriate precautions against fire damage in 1972.

Ahlbrandt found that a private firm in Scottsdale, Arizona, provided fire protection at lower cost than publicly operated fire departments in Washington State. While one example is insufficient to prove or disprove a hypothesis of this importance, the theoretical issues raised above do suggest that the private alternative to public supply be given careful attention.

If the efficiency of municipally supplied services is to be improved, or if private companies are to be effectively monitored, and if new techniques and equipment are to be introduced, then there must be a method of measuring efficiency. This must involve estimating the production function for fire protection--the relationship between the quantity of inputs, labor, equipment and stations, and output, the reduction in damage, injury and loss of life due to fire.

Unfortunately, fire damage in an area is a function of many factors, including the climate, the type, age and distribution of the housing stock, the population, the type, level and distribution of manufacturing and commercial activities, and the local building codes (and the level of enforcement), as well as the level of fire protection services. In addition there is a strong stochastic variation in the level of damages in an area over time. Identifying the influence of the different levels and types of fire protection is a difficult statistical problem requiring a great deal of data. Until standardized techniques for collecting data from fire departments are adopted, and the appropriate information for different communities is assembled, no full, methodical analyses will be possible.

During 1943 Simon, Shephard and Sharp compared fire loss per $1000 of property in Berkeley and Oakland in an attempt to compare efficiency, and made an attempt to screen out the effect of factors beyond the control of the fire departments. They provide a useful guide to the collection of loss data from local fire department, building department, and property tax files. They provide, too, a useful warning against drawing premature conclusions from such comparisions.

> "Further examination of these data emphasizes some of the cautions which must be observed in interpreting classified loss experience. In Oakland, for example, all unsprinklered frame structures showed a loss ratio of $1.26 while all unsprinklered masonry-walled structures showed a loss ratio of $1.65. At first glance it would appear that the loss experience of the latter class was poorer than the experience of the former class. Further study of the data, however, shows that the higher loss ratio for masonry-walled structures is due to the greater preponderance of mercantile and manufacturing uses (which have a higher loss ratio than residential uses in comparable structures) in that structural class... hence a weighting bias was introduced because of the different distribution of occupancies in the two classes of structures."

Ahlbrandt used the municipal grading index as a measure of the level of fire protection output. Rather than use output as the dependent variable, he used per capita costs, and attempted to explain cost variations in terms of the type of equipment employed and the level of output. He collected data for cities in Washington and Arizona and found that the relationship between per capita costs and the included independent variables was similar in each state. Per capita costs were below their predicted level in Scottsdale, Arizona, served by a private fire-protection firm. Research to quantify the efficiency of private versus public supply of fire suppression more conclusively and in more detail would be valuable.

The fire problem in the United States centers on housing. So does the construction industry. The distribution of new construction in 1971 shows the greatest value of new construction put in place in the residential category, 39 percent. Likewise, about one-third of fires and fire-caused damages occurred in residential buildings. A careful estimate of fatalities and injuries caused by fires in New York City over a three-year period places 82 percent of all injuries and 76 percent of all fire fatalities in residences.

Housing is a major area of continuing replacement. This fact has motivated a great deal of attention from the fire research community since the problem is important and the setting is being rebuilt continually. Analysis of the dynamic turnover of the housing stock is important because research payoffs depend on being able to change housing. Although a great deal of new housing is built each year, a lot of housing is on hand and will be in use for some time to come. The half life of the entire housing stock in the United States estimated by us is about 25 years. Half life is defined here as the time span such that half the housing units in use at the end of the span were built since the beginning of the span. If a housing code change were adopted in 1975 and all new housing reflected the change, then in 2000 half of the housing existing would bear the mandated attribute. That is an average for all housing and will vary considerably over geographic location and building type. However, it suggests that code-based strategies will take a long time to reduce the fire problem, expense and effectiveness aside.

Among research topics related to housing, detector-alarm systems can provide two benefits by: (1) warning building occupants, and (2) speeding the arrival of fire departments. Such systems can be made cheaply, and innovative suggestions to reduce the false alarms caused by oversensitive detectors have been discussed in the literature. Private concerns will continue to develop household units. Publicly supported research would be valuable in developing a system connecting household units to public fire departments.

A demonstration-experiment in occupied housing could provide the necessary information and with relatively little additional effort, assess costs and the substitutability between detector-alarms and fire-department services. In areas of low population density, alarms may reduce average fire department response time greatly. It is entirely possible that such a department might improve its protection more by installing detectors in residences than by increasing its stock of vehicles.

Field development of detector-alarms and the communication systems connecting households to fire departments is a high-priority research task. Since such a system could be added to existing housing units, the long life of housing will not hinder implementation of the strategy.

The contents of buildings in general and housing occupancies in particular may have a much shorter half life than the buildings they fill. The 1974 Joelma Building fire in Sao Paulo, Brazil destroyed all floors above the level of ignition except one that was unfurnished and in a state of construction. A greater potential for impact on fire-caused losses may obtain in the area of contents than that of housing structures. This is not to minimize the substantial benefits provided by research in the area of structures, but fire research resources are scarce. Thus, efforts should be made to invest them in the areas of greatest probable impact. Shortsighted strategies are not recommended, but time is a valuable commodity. A successful research plan produces tangible results sooner rather than later.

Much current regulation of hazardous materials focuses on the qualitative aspect of hazards. Some focuses on proportional measures such as the optical density of smoke *per unit mass* combusted. But relatively little attention has been focused on the absolute magnitude of material hazards (i.e., the total quantity in an occupancy's volume). For example, paper is not considered toxic, but it is well known that the loading of structures with large amounts of flammables like paper presents a prime fire hazard. No doubt officials concerned with codes have pondered the problem. The loss rates caused by fire that prevail in the United States may be causally related to high loads of disposable combustibles in residential occupancies.

These factors form two important research topics (1) how large is the problem, and (2) what mechanisms are likely to be effective at reducing the patterns of building use that produces hazardous loadings of flammable materials? A modest effort would produce a rough--and sufficient--answer to the first question.

Identifying regulatory mechanisms that would be effective is a difficult problem. Codes may be impractical for housing units because millions of units would have to be checked regularly to effect significant changes. Legal approaches through liability law might be effective.

Insurance, discussed later, may be effective in providing incentives to occupants to minimize this form of hazard alone or in combination with code systems or new liability standards. But no one knows. Exploring this range of attacks on the quantitative aspect of housing fire hazards is an important research topic. Private concerns probably do not have incentives to take the necessary broad approach so this kind of work may best be funded publicly, perhaps in connection with the study of regulatory mechanisms.

The problems faced by fire departments vary somewhat by the population of their jurisdiction. The population of the United States is just about uniformly distributed in thirds over large cities (population > 100,000) small to medium cities (10,000 < population $\leq$ 100,000), and small cities and rural areas (population $\leq$ 10,000). Since the population in each category is large, their particular fire problems rate equal importance. Tight budgets direct attention to the most important fire problems, but distribution of *population* by *city size* doesn't help identify them.

However, the distribution of *cities* by *population size* is quite uneven. Of all cities 10,000 or larger in size, 83 percent fall in the 10,000 to 50,000 range. Assuming that cities have one fire department each, we see that a very large proportion of all fire departments belong to cities in the 10,000 to 50,000 range. Much of the demand for improved firefighting technology comes from fire departments, and this distribution of them shows where the audience for both new ideas and the market for goods and services lies.

How do cities rank fire protection in their budgets? Above parks and recreation and below police protection. Budget allocations for police and fire have remained about the same proportion of total municipal budgets while utilities and highways have declined, and the allocations for education have climbed. Fire protection takes only 5 percent of the budget of cities, but it has occasionally become a major issue in political struggles over rising municipal budgets.

The structure of fire departments' budgets is important because it determines their margin for innovation and areas of greatest current investment. Labor takes the lion's share of fire protection budgets, ranging from 82 percent of the total fire department budget for cities in the 10,000 to 25,000 range to 92 percent for cities over 500,000. Since labor consumes so much of fire departments' budgets, reductions in labor cost or increases in productivity will bear direct, favorable effects on the level of fire protection and the cost of attaining it.

Volunteer firefighters are an important factor in the American fire service. The distribution of fire departments by type shows that over half of all cities under 10,000 (and nearly 3/4 of those under 5,000) are volunteer. This emphasizes two policy issues: (1) At what size (and other characteristics like population density) does it become more efficient for a city to maintain a full-time staff of professional firefighters, and (2) What aspects of equipment and coordination of volunteer departments could benefit most from (or, are in greatest need of) research-developed innovations?

Research on fire department efforts may be divided into three aspects: (1) procedures, (2) equipment, and (3) personnel. Procedural changes are attractive because large expenditures are not necessarily required, although changing an organization can be difficult and learning new procedures takes time.

Capital purchases and labor are direct expenses. Some changes of them can be implemented by administrative authority, but most of those expenses are recurring and fairly inflexible.

Much is made of the potential for new technology in firefighting. How big is the market for it? The total annual expenditure for non-labor items in fire department budgets was about $300 million in 1972. Since much of that consists of maintenance and direct operating costs (e.g., gasoline, tires, etc.), only a portion of this expenditure could be used to buy new technology. Over half of this total expenditure is made in cities with populations under 100,000 where we estimate that over 80 percent of professional firefighting agencies are based.

So the market for new technology is not large by national standards--perhaps half of non-labor expenditures, $150 million annual national total. The buyers are mostly small and scattered. These factors weigh against large private developers', who have high technology know how, investing in research on technological advances in fire-fighting equipment. Two approaches can be taken by planners of publicly supported fire research: (1) invest in research to create and evaluate technical aids, or (2) invest in research on mechanisms to support the kind of market that high-technology firms require before investing in research and product development. Federal cost-sharing programs linked to standardization of products and purchases are one strategy to develop and disseminate technology. Research into such mechanisms may produce feasible plans to make the market for fire-protection equipment more attractive to large firms capable of sophisticated research, development and manufacturing.

Labor is a likely topic of fire research because labor is the largest component of the cost of fire suppression by fire departments. A 10 percent reduction in labor cost means a nearly equal reduction in total fire-suppression costs. A 10 percent reduction in capital equipment costs would produce only a 1 percent reduction in total fire-suppression costs. The labor dimension of fire-protection has received less attention from researchers than procedural activities and the development of equipment. The traditional emphasis of fire research in the area of fire departments, while producing valuable contributions to public safety and economy, might fruitfully be shifted towards the costs and characteristics of labor inputs to the "production" of fire suppression.

The time between ignition of a fire and receipt of alarm by a fire department dispatcher is widely perceived as a leverage point in the attack on fire. Time elapsed during this part of the fire life-cycle may often be an order of magnitude greater than the time necessary to get firefighters to the fire after an alarm has been issued.

Detectors located in residential and commercial occupancies connected by telephone lines to a central processing computer and dispatcher offer potential savings in the time lag between ignition and alarm. Detectors are well developed and simple algorithms to separate nonserious from serious fires have been proposed elsewhere.

A field experiment of substantial size on a detector-alarm system could provide valuable information on three issues:

- The time-severity profile of fires. How does loss of life and property correlate to time elapsed after ignition, by cause of ignition, occupancy, location, and characteristics of persons involved?
- Discrimination of potentially dangerous fires. Detectors can sense small fires, but how can the nondangerous cooking fire be discriminated from the potentially dangerous, smoldering cigarette-caused furniture fire?
- Assessment of the economical substitutability of detector-alarm systems and fire departments. In the particular economic sense, manned fire equipment and detector-alarm systems may be substitutes for each other. This does not mean that one might entirely replace the other. Rather,

> it is possible that a fire department could increase the level of fire protection produced more by adding a detector-alarm system than by making the same investment in extra equipment or labor.

The experiment suggested above may provide answers to these questions. The information would be valuable to municipal fire departments. No private firm is likely to mount independently such an investigation into private residences and the operation of a public service, so it would be necessary and may be worthwhile to support such research publicly.

Small, adjacent fire departments might increase the level of fire protection they produce by consolidating. This topic has received a great deal of publicity, but we found no conclusive studies that have measured the costs and benefits and examined thoroughly the details of consolidating fire departments.

Municipal officials need to know if their cities will benefit from a consolidation and what particular problems might arise as a consequence of consolidation. Thus, case studies of consolidated departments already in existence are warranted. Simply by examining fiscal records before and after consolidation of the communities involved, estimates of costs may be obtained (both of transition and of routine operations under the separate and combined organizations). Taking account of changes in population, geographic jurisdiction, housing stock, commercial activities, etc., against changes in the incidence and destruction of fires will enable a judgment on the effect of consolidation on the fire problem. A detailed accounting of changes in firefighter training, facilities, and the like will aid the assessment of benefits produced.

The product of this research would provide quantitative estimates of the costs of consolidation against the effects produced. This work should examine a variety of size, location, and type of cities to identify what situations, if any, indicate that consolidation is beneficial.

Insurance transforms an uncertain chance of loss into a certain and fairly constant cost per unit of value insured. To the extent that an item at risk can be replaced through money, insurance can reduce the impact of unpredictable hazards like fire. The cost of fire isn't eliminated, just the uncertainty. Organizations and individuals often go to great lengths to minimize uncertainty.

The loss caused by destructive fires is actually increased by the use of insurance. The cost of doing business and the profits accumulated by insurers must be paid by the insured in addition to the cost of fire damages. Even in a perfectly competitive insurance market where profits weren't accumulated, the cost of doing business would remain. The reliability of insurance firms may be imperfect, adding further to the indirect cost of fire. Finally, the price and availability of insurance may be varied in selective, discriminatory ways by sellers, that are inconsistent with general social welfare.

Insurance adds some costs to the damages caused directly by destructive fires. The first research questions are, which if any of these costs are large, relative to the direct cost of fire destruction, and what potential exists for reducing any significant costs? In addition to these cost-related issues, how might insurance be used to influence individual and organizational behavior to minimize fire risks and losses?

Assuming that only half of the $7.7 billion net premiums for all fire-related lines of insurance were specifically for fire protection, insurance still represents a larger share of the cost of fire than do fire departments. Fire department expenditures amounted to about $2.7 billion for cities of 10,000 or more people, in 1972. Based on a review of the fire research literature conducted by Arthur Swersey and others at The New York City-Rand Institute, fire insurance has received much less attention from researchers than have fire departments.

An important study of the market for property-liability insurance was made by Joskow. His analysis shows that prices have not been competitive except in states which have open-competition insurance laws, a recent phenomenon in most. In that analysis, insurance companies are treated as firms marketing one item, insurance. However, insurance firms also are investment companies. They have substantial reserve funds to cover their insured risks. A ten-year average for stock fire and casualty companies shows underwriting profit to be negative over the period and investment income large, positive and growing at a rate that indicates substantial capital accumulation.

Is ten years the short run? That doesn't seem likely. But if it's the long run, why don't firms get out of the insurance business? Perhaps they operate like banks and not only can but *must* pay money in the form of underwriting losses to borrow capital. Joskow touches on this in assessing the industry's profitability and in constructing the economic model examined. However, he does not explicitly consider the influence this will have on firms' behavior. For example, firms may have an incentive to delay payoffs for damages since their income is derived from investing premium income and equity capital. Since firms gain little profit from underwriting, they seem to have little incentive to improve their marketing efficiency.

Insurance companies sell two products: insurance and investment capital. Research on the implications of insurance companies' character as two-product firms may provide information useful to regulatory agencies and to legislatures considering revision of controls on insurance. Payment practices such as time between filing claim and receipt of payment and assessment of extent of loss may be affected by the nature of insurance companies. Marketing practices may also be affected. The objective of research in this area would be to identify factors controllable by law or regulation that could be altered to improve the quality or reduce the cost of insurance to consumers.

One of the chief limitations to using insurance rates as an incentive to promote fire safety is ignorance about the known risk of fire associated with measurable factors of buildings, occupants and their environment. The high level of uncertainty about the causes of fire results in fire costs being shared more uniformly than if more detailed quantitative information on the risk of fire by factors of causation were available.

Research to improve knowledge of the probability of fire by cause would enable more accurate rate setting by insurance companies which would tend to lower the social cost of insurance. Safe practices by builders and occupants would be directly rewarded financially. Better knowledge of the risk of fire would enable renters and buyers of buildings to shop more effectively. Housing prices would be affected by such informed shopping.

The data collection effort necessary to generate information on the probability of fire associated with various factors will be large. The best source of information may be the policy and claims records of insurance companies. To be effective, initial research on this topic would have to focus on a manageably small aspect of fire such as single-family-unit dwellings.

Why has the insurance industry not produced information on fire similar to that used in setting automobile insurance rates? For one thing, fires occur less frequently than automobile accidents. The data sufficient to assess probabilities confidently would require a larger set of observations on individual policies than is the case with auto insurance. For another thing information on predictors of fire (which are as yet mostly unknown) may not be in policy or claims records. Finally, insurance companies have relatively little to gain by acquiring such information. Their industry works well for them under present circumstances. The beneficiaries of better information on fire risks are low-risk, individual policy holders and society at large.

Because this kind of information is easily transferred, private entrepreneurs do not have strong incentives to produce and market it. They would have a hard time keeping the information limited only to its purchasers, and most of the benefits would not be capturable by the marketing firm. Thus, public support for an effort to generate detailed information about the risks of fire seems appropriate.

These areas represent a limited collection of fire research topics. Some of them may yield substantial impacts on fire problems.

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