PART II

REVIEWS, APPENDIXES, AND BIBLIOGRAPHIES
INTRODUCTION

The second part of this report contains:

- Reviews of the policy-related fire literature.
- Appendix A, the methods and sources used for searching the literature and an address list of sources of fire literature.
- Appendix C, which describes one fully implemented and 12 proposed computer-aided command and control systems.
- A bibliography of the publications that were reviewed.
- A list of all authors of the publications that were reviewed and the number of the reviews.
- A selected bibliography of other references, including all publications referred to in Part I of this report.

Each review is organized as follows:

- The author, title, publisher, and date of publication being reviewed. Each review is numbered according to the chapter of Part I in which its subject is discussed. E.g., R3-3 is the third review on the subject matter contained in Part I, Chapter 3.
- A short abstract of the publication.
- The primary audience of the publication.
- A statement of the issues treated in the publication.
- An assessment of the publication's policy utility.
- An assessment of the validity of the publication's methods and results. When appropriate, internal validity (were the methods appropriate?) and external validity (do the results agree with others or apply elsewhere?) were assessed separately.

For some publications this treatment is sufficient. For others, the review also has a detailed summary or discussion of the publication. In general this fuller treatment was given to publications that treated more important subjects and to those whose methods and results were more interesting or more controversial.

An exception to this format is the treatment of publications by members of The New York City-Rand Institute. Since this report has been prepared at the Institute and since Institute publications are reviewed internally before being released, we chose not to evaluate the internal validity of these publications. An outside assessment of many of these papers is contained in the review of the fire protection literature done at the Georgia Institute of Technology. (See Related Research Supported by the National Science Foundation at the end of this report.)

We attempted to fit the level of detail in each evaluation to the publication in question and to the needs of the reader. For publications that were obviously poorly reasoned, we did not go into detail unless it appeared that the errors were likely to be repeated or the work likely to be used as a foundation for other work. For important publications, methods and results were often discussed in detail, so the
reader would be able to contrast them with less worthwhile work. We felt that more rigidity in format and length of the reviews would not serve our purpose of giving the reader an appreciation of the content, importance, and validity of each publication.

The reviews are grouped by topic. We numbered and organized them according to chapters in Part I. Within the major headings, reviews are grouped by subtopic usually in the order they were treated in the chapter. We tried to order the reviews within a chapter so that it would be reasonable for the reader to look at them in sequence. When it appeared appropriate for this purpose, we put reviews of earlier publications before those of later ones, more detailed reviews before less detailed ones, and reviews of more important publications before those of less important ones.

Within each review, references to other publications are handled as follows. If the publication has also been reviewed, the reference is of the form “Hogg (R7-7),” directing the reader to the review. If the publication has not been reviewed, the reference is of the form “Emmons (1974),” with the full reference given in the bibliography of other references.

APPENDIX A

This appendix describes the methods and sources we used for searching the literature. We have also included the names and addresses of sources of fire literature for the convenience of the reader.

APPENDIX B

This appendix reproduces the Fire Problems Questionnaire administered to our Advisory Panel.

APPENDIX C

This appendix describes computer-aided dispatching systems. In each case, we give the city involved and some of its characteristics, the computer manufacturer (if known), whether the system is joint with other agencies (police, ambulance), the functions performed by the computer, an estimate of the cost, the status of the system as of late 1974, and the name of an appropriate person to contact.

BIBLIOGRAPHY OF PAPERS REVIEWED

This bibliography gives the author, title, publisher, date, and review number for every publication that was reviewed. It is organized alphabetically by author.
AUTHOR LIST—PAPERS REVIEWED

This is an alphabetical list of individuals and organizations. It gives the review number of every publication of which the individual or organization is an author. For publications with several authors, all authors are included.

SELECTED BIBLIOGRAPHY OF OTHER REFERENCES

This bibliography is an alphabetical list giving author, title, publisher, and date of other references. A considerable number of publications are referenced in Part I and Part II but are not reviewed. These publications are listed here. This bibliography also includes a selection of other publications, neither reviewed nor referenced, that we felt might be of interest to the reader. Among the publications that we gathered were items of limited value to an audience concerned with policy, but we did include these publications in this bibliography.
### AUTHORS OF REVIEWS

<table>
<thead>
<tr>
<th>Name</th>
<th>Subject Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philip Armstrong</td>
<td>Organization; Prevention; Life Safety</td>
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<td>Grace Carter</td>
<td>Deployment; Fire Department Operations</td>
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<td>Jan Chaiken</td>
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<td>Hope Corman</td>
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<td>Thomas Crabill</td>
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<td>David deFerranti</td>
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<td>Edward Ignall</td>
<td>Organization; Cost, Distribution, and Effectiveness; Early Detection and Sprinklers; Fire and Smoke Behavior; Life Safety; Deployment; Fire Department Operations; Reporting Systems and Statistics</td>
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<td>James Marker</td>
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<td>Arthur Swersey</td>
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<td>Richard Urbach</td>
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<td>Joachim Weindling</td>
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REVIEWS

R3-1

Abstract: This consultant's report to the City of San Anselmo compares local services and finances with likely public desires and considers alternatives to improve the services provided by local government. Intercity improvements (among three small cities) are analyzed. Formal cooperation, joint police and recreation departments, the use of special districts, and city merger are all examined. A plan is developed for consolidation of four city and district fire departments into a single agency serving incorporated and unincorporated territory. Minor improvements are proposed in San Anselmo's internal governmental organization and procedures concerning financial control, police, fire, public works, parks and recreation, and space utilization.

Audience: Everyone.

Issue: Are regional consolidated fire departments more efficient than separate local departments?

Policy Utility: Medium.

Internal Validity: Adequate.

External Validity: Adequate.

Discussion: This report touches only briefly on fire damages. Instead, attainment of improved insurance class rating through supplying specified inputs (men, equipment, organization) is the dominant justification for consolidation. Since the report takes the insurance rating system as given, its recommendations are perfectly valid internally.

This study agrees with other reports we have located. However, a claim to general validity is supported only by consensus and by projected (rather than observed) cost savings. All in all, the arguments for consolidating fire departments in regions composed of small cities near each other are compelling because of easily attainable economies of scale. However, there is also a movement toward and belief in consolidating local government services that would make it risky for a consultant to buck the trend and be labeled as backward or controversial. Thus, some caution is in order before one embraces the virtues of jurisdictional consolidation.

This report and others like it form a base of evidence justifying and popularizing fire department consolidation. Assuming that is a valid policy, this evidence is good as well as useful for effecting change. However, the lack of follow-up cost-benefit analyses and the reliance on inputs (men, equipment, organization) as proxies for output (improved fire protection) are weaknesses.

R3-2

Abstract: This is a consultant's report to the City of Peoria, Illinois on that city's partially combined police and fire departments. It is the only significant quantitative analysis of integrated police-fire activities that we have found. Available data from the city and difficulty in measuring service output prevented FSSI from executing a formal benefit-cost analysis, but as much quantitative assessment as possible was made. Additionally, the firm studied the city thoroughly in person and evidently gathered many detailed first-hand opinions. Background, methodology, analysis, and recommendations are presented in detail. The second volume of the report contains the technical appendixes comprising the data and evaluations.

Audience: Primarily city administrators.

Issue: Are combined police-fire departments more efficient than separate departments?

Policy Utility: Potentially high.

Internal Validity: Mixed, some internal inconsistencies, some good analysis.

External Validity: Adequate and consistent with Cunningham's work (see R3-6).

Discussion: The main problem with the analysis is that the authors do not seem to distinguish between absolute and relative or ratio measures. For example, a five-year moving average of total city fire losses is shown in one chart. It rises steeply just before the city annexed an adjacent area. Since the five-year moving average is presumably a central (rather than forward or backward) average, the annexation may account for the steep damage rise before the annexation date. Computation of damage per capita would have been more appropriate.

The report stands out in the thoroughness with which it investigated such issues as personnel morale and implementation of the consolidation concept in details such as using common dispatching stations. The partial combination in Peoria was not successful, because of lack of attention to detail at every level. There was too little effort to maintain personnel morale, unified and continuous top administration, coordinated station house construction, and adequate training of cooperative patrolmen in fire-fighting skills. The study contains no apparent logical errors and, with the exceptions noted, seemed generally consistent (i.e., valid) internally.

Curiously enough, the authors apparently did not
know of Cunningham's (R3-6) work, although they used the work of James (R3-7) and of More (R3-8). Nevertheless, the problems cited in the Peoria case are those listed by Cunningham (except that no extreme-demand disaster occurred during the period). The cost analysis showed that rising labor wage rates rather than rising employee numbers account for most of the expenditure increases, tending to discount the arguments of James and More.

This report does not provide the basis for a general recommendation for or against functional integration of fire departments. However, it clearly and solidly demonstrates that integration requires very careful attention to detail over a prolonged period of time and a unified management structure overseeing the transition. It may be possible, using the data in the report, to make better computations that show more conclusively the efficiency of integration in Peoria.

R3-3
The Sierra Group, Pittsburgh-Antioch Area Fire Protection Study, San Francisco, California, April 1, 1974.

Abstract: This consultant's report is similar to the Baxter, McDonald & Company report done for San Anselmo (R3-1) although this study focuses entirely on fire protection. The scope of work included a review of existing fire problems and fire-fighting capabilities, analysis of two alternative fire department organization concepts (a single consolidated district and two enlarged, separate districts), an implementation plan, and an analysis of implementation costs. This report is longer than the Baxter, McDonald study and particularly thorough on projected cost and finance details. The analysis of implementation problems is detailed and thoughtful.

Audience: Everyone.

Issue: Are regionally consolidated police-fire departments more efficient than separate local departments?

Policy Utility: Medium.

Internal Validity: Adequate.

External Validity: Adequate.

R3-4

Abstract: This short paper reviews the history of consolidation of fire districts in Contra Costa County, California and cites the benefits. Consolidation was proposed and rejected in 1935 and 1958. The article implies that the 1961 Fire Reorganization Act of the County Fire Protection Districts of California did not have much to do with the consolidations within Contra Costa County. That began in 1964, stimulated by the incorporation of Pleasant Hill, which straddled two existing fire districts in Contra Costa County. Later, a County Board of Supervisors action furthered consolidation in 1966 as did a subsequent vote of the people in 1968 on another annexation. Many benefits are cited such as increased service capability and reduced fixed costs. The county's overall insurance rating became uniform at (an improved) Class 3, and its tax rate went down during these years.

Audience: Primarily city administrators.

Issue: Are regionally consolidated fire departments more efficient than separate local departments?

Policy Utility: High.

Internal Validity: Not applicable. This paper recites some history and states benefits.

External Validity: There are many similar, growing areas that could benefit from consolidation if the success in Contra Costa is real and transferable. What is missing, however, is the "how" behind the events. The article makes it sound like a series of fortuitous events, although it would seem that there must have been some highly organized, unpublicized activities going on.

R3-5

Abstract: This dissertation reviews the theory of open systems. The author then presents data from a survey of fire chiefs and other officials in San Diego County concerning existing fire services and fire problems and makes a recommendation for county-wide fire service consolidation. The appendixes contain reference information on California legislation pertaining to local government and fire services, fire insurance ratings, and powers of the County Board of Supervisors.

Audience: Everyone.

Issue: How can fire departments be organized most efficiently?

Policy Utility: Low.

Internal Validity: Very weak.

External Validity: Very weak.

Discussion: The lengthy discussion of open systems is not followed by use of the theory to induce a behavioral model of the county's fire service (one of the stated goals of the study). There is no analysis of survey response bias nor was there (evidently) any pretesting of the survey instrument. The logic behind the ultimate recommendations remains elusive. It appears to be based in small part on opinions of persons surveyed and in large part on logic ungrounded in empirical knowledge. Fire loss data are missing as is any careful analysis of economies obtained by improving insurance class ratings.

No comparisons with other areas or before-after
changes are made. The work is neither thorough nor well organized. Problems anticipated in implementation are solved tautologically. For example, selection of a single fire chief is expected to be difficult. The recommended solution (p. 159) is "that this be determined by mutual consent amongst the chiefs and district boards, city councils or commissions."

R3-6

Abstract: This massive dissertation (well over 600 pages) is the best comprehensive review and analysis of police-fire department integration we have seen. The author clearly defines the problem to be highly reliable delivery of emergency public safety services under routine and extreme conditions, sets forth a methodology of structural-functional analysis of organizations, and reviews the available literature thoroughly and fairly critically. This analysis is purely qualitative and is distinguished from other works in the field by: recognition of the real costs associated with overcoming political resistance to integration; solid logic; careful, sequential organization of the analysis; and thorough recognition of issues and problems (e.g., costs of reestablishing separate police and fire departments if integration is implemented and later abandoned). The author reviews the British and French-Canadian experiences, and notes the similarities to and dissimilarities with the American experience.

Audience: Everyone.

Issue: Are combined police-fire departments more efficient than separate departments?

Policy Utility: Potentially high.

Internal Validity: Adequate.

External Validity: Good. This work makes well-documented conclusions, contrary to those of James (R3-7) and More (R3-8) who do not document their analyses well.

Discussion: The author's well-substantiated principal findings are that: (1) under short-run situations of high demand for fire protection such as caused by German bombing of British cities, combined police-fire departments often failed to provide effective fire suppression, and (2) over the long run the British procedure of combining fire protection agencies as a subordinate part of police agencies led to reduced morale, budgets, and quality of personnel in the fire-fighting divisions.

Although it would be valuable to have benefit-cost comparisons and estimated production functions for separate and combined police-fire departments, this qualitative analysis is internally consistent. The traditional bromides ("a day's work for a day's pay") are carefully avoided. The analysis is well organized though voluminous, and the perspective is quite broad. Organizational and individual behavioral dynamics (and consequent constraints) are recognized. Structural-functional analysis is derived from the most explicit and well-developed branch of modern sociological theory, and the author uses it well as a basis for discussion: identifying role functions and their relative arrangement (i.e., the structure).

The author shows broad and deep understanding of the real community and cultural environments of fire and police departments and adopts a neutral tone of discourse (in contrast to others). A similarly subtle perception of the problems faced by such urban service departments is shown particularly by recognition of the distinction between routine and extreme demand conditions. Many events and reports are utilized, and all are thoroughly covered. A complex qualified case is made for the findings from the case-study data. The study is better than other works cited because of the more thorough and critical use of the same sort of information.

As it stands, the report is a formidable piece of academic work. The results are put in a policy-useful conclusion, but they need to be disseminated in a more penetrable document. Further analysis of a quantitative nature would be helpful in buttressing this analysis.

R3-7

Abstract: This book and a companion work by the same author (Police and Fire Integration in the Small City, Public Administration Service, Washington D.C., 1955) address the issue of integrating police and fire departments in one city into one unified public safety department. It is not an academic or research-oriented book, but it clearly intends to promote and effect policy changes in local government. It advocates integration. There are two parts: a review of municipal public safety services and a plan for integrating police and fire departments. The logic and justification supporting integration are presented in the first section.

Audience: Primarily city administrators.

Issue: Are combined police-fire departments more efficient than separate departments?

Policy Utility: Low.

Internal Validity: Weak. The author considers only the advantages of integration, discounting possible disadvantages.

External Validity: Weak. The author cites the British experience briefly and simply ignores the service break-
down problems that occurred there during the Blitz. In the many integrated police-fire units then in existence, no quantitative analysis is done to verify the proposal that states as its own merit a quantitative merit: more effective service delivery at reduced cost per unit of service.

**Discussion:** That police and fire departments should be integrated is based on two premises (extracted with some difficulty from a long, rambling text). First, modern police and fire departments are so highly differentiated within themselves by specialized functions that interdepartment variations by functions are small in comparison. Second, modern radio dispatch equipment eliminates the need to have groups of firefighters clustered around their equipment awaiting calls for service. Accepting these two premises leads to the finding that firefighters waiting in fire houses could, if trained in an integrated public safety role, be performing necessary administrative tasks during their inactive periods. Likewise, policemen could perform such preventive tasks as inspection and public education in the course of their routine patrol tasks.

The author uses the observation that variations within each service lessen interservice differences to justify integration at the administrative level. But it is an unclear, imprecise discussion; issues, assumptions, and justifications are not clearly laid out. No explicit methodology is used. The importance of cost control is invoked but not really analyzed. Two realities are ignored: Police departments and fire departments have strong survival instincts, and fire departments actively fear subsumption by police departments under integration; and individual role performance is a strong function of morale, and integration obviously could degrade morale. The first reality is a barrier to implementing that can be overcome only at a cost (political capital, time spent persuading, etc.) that can be very large. The second is a cost incurred after implementation in the form of reduced service delivery.

This book has probably encouraged most of the police-fire integration in the United States in the last 20 years. At this point, it is difficult to accept its findings, which is why its effective policy utility is rated low. Integration may have merit under some circumstances, but there are two parts to it: integration of the administrative superstructure and integration of the functions of line personnel. The first is really elimination of duplicated roles. For example, a (financial) controller is a controller, regardless of the department being served. Thus, an integrated department would have one controller where two existed before, affecting a cost reduction by eliminating duplication. But that is simplistic and naive with respect to theories of organizational efficiency and behavior available in the early 1950s. Integration of line personnel means training individuals to do more than one role—i.e., developing more broadly skilled individuals (not necessarily more highly skilled).

**R3-8**


**Abstract:** This work (the book is taken directly from the dissertation) discusses the background of (emergency) public safety services, defines functional integration of fire and police departments, discusses various opinions and issues, and presents a plan for consolidating separate police and fire departments. The approach of the book is to cite the experiences of several cities that have tried consolidation and to present background statistics on the rising costs that cities face in providing urban services.

**Audience:** Primarily city administrators.

**Issue:** Are combined police-fire departments more efficient than separate departments?

**Policy Utility:** Low.

**Internal Validity:** Weak.

**External Validity:** Weak. Uses the positive French-Canadian experience while ignoring the British difficulties.

**Discussion:** This book has the same flaws as the James work (R3-7). In addition, the author has reviewed case studies of a great many consolidation efforts, partially by original survey. The author uses two stated methodologies: (1) documentation, by which is meant recitation of the experiences and opinions of others with little or no analysis, and (2) sampling "by regular intervals" of over 3,000 police departments listed in "Crime in the United States—1965" (an F.B.I. document), by which is meant an unstratified systematic sample without a random starting point. A growth rate trend in the total national number of municipal public safety employees is cited. However, clearly the appropriate measure is employees per capita computed by city groups disaggregated according to population. The author attempts to justify functional role integration by citing a trend toward increasing intradepartmental role differentiation, just as James (R3-7) does, although not quite as explicitly. Deteriorating cost-effectiveness is cited (in different terms, among which is the remark, "There would seem to be little justification for perpetuating a system whereby protective employees are not required to do a day's work for a day's pay"). but scant evidence is shown to prove the cost-effective merits of consolidation.

The author noted the French-Canadian experience (a tradition of police-fire consolidation in small municipalities) and drew on it as unqualified evidence supporting the case for consolidation in the United States. No recognition of cultural and organizational-tradition differences was shown. The author drew on the British experience, but somehow missed the recognized breakdown of
consolidated British police-fire departments during the Blitz. Separate departments have the advantage that during periods of extreme demand for police and fire service, a communications breakdown leaves a definite number of persons in each of the two roles. Acting independently, small groups of both services can act more effectively than dual-role personnel, who would suffer role confusion and subsequent indecisiveness under communications breakdown. Even if communications didn’t break down during an extreme situation, the allocation problem for the central dispatcher would be enormously complex. More shows no recognition of this.

The author has stronger identification with police than with fire departments (e.g., the preface by a police chief, use of police F.B.I. data sources as a basis for sampling municipal departments, and the author’s noted chairmanship of a law enforcement and administration academic department).

R3-9

Abstract: There are 16 independent fire departments in Montgomery County, Maryland. At the time of the study, eight of the departments were volunteer, two were fully paid, and six were combination paid and volunteer departments (about 75 percent volunteer manning on the average). The study showed that both paid and combination departments performed about equally well.

Audience: Everyone.

Issue: Paid versus volunteer departments.

Policy Utility: Some, although there are questions of internal validity.

Internal Validity: Questionable.

External Validity: Questionable.

Summary: Eight "measures of performance" were used to compare the departments.

(7) Fire protection cost = 
\[
\frac{\text{fire department expenditures}}{\$1000 \text{ of assessed valuation}}
\]

(8) Operational cost = 
\[
\frac{\text{fire losses} + \text{fire department expenditures}}{\$1000 \text{ of assessed valuation}}
\]

Bennett finds that, in general, paid and combination departments perform significantly better than volunteer departments. The analysis shows that "a group of largely volunteer departments (which the combination departments are, in fact), employing paid personnel for quick response and continuity of experienced leadership, can perform with an effectiveness equal to that of fully paid units." Further, the analysis suggests that the combination departments provide fire protection services at a lower "cost" than the fully paid departments. The author gives the following possible explanation for these results: "The combination departments can maintain the limited number of paid personnel necessary for quick response and still have the advantage of the manpower resource of the volunteer fire-fighters." That is, the volunteers have more manpower but it takes longer to get there.

Discussion: The author himself points out the difficulty in drawing strong conclusions from his study. He says,

The overall problem of fire protection performance is quite complex, and is affected by more factors than just the form of organization of the individual fire department. Further studies are required before the reasons for the differences in performance can be clearly established, and the proper measures to be taken can be defined in detail. An attempt was made to look more deeply and identify the particular factors that contributed to the above results. It was found that the necessary information for an analysis could not be obtained. In general, the data needed to determine the relative contribution of factors such as distance between stations and fires, response time, type of structure, level of personnel training, number/type of apparatus dispatched, etc., either did not exist, was extremely difficult to gather, or was not in usable form.

The problem with this study is that it is not specified how the various areas compare with each other. It looks like the areas in which there are volunteer departments may be poorer (have lower assessed values), and have higher fire incidence. The higher losses may have little or nothing to do with fire department response.

R3-10
Abstract: From the preface: "The purpose of this book is to provide the fire chief and other fire command officers with a better understanding of fire safety problems and to set forth accepted administrative methods for getting work done." Its chapters deal with objectives, insurance rates and grading, organization, personnel management, water supply, purchase, maintenance, and design of buildings and equipment, deployment of men and equipment, communications and alarm systems, firefighting operations, legal and organizational aspects of prevention, investigation, and record keeping.

Audience: Fire chiefs; everyone.

Issue: What are the administrative needs of a fire department?

Policy Utility: A carefully written introduction and references that cover the right topics; therefore very useful.

Validity: Not applicable.

R4-1

Abstract: The only way we can measure fire service effectiveness is to observe actual losses. But losses depend on factors specific to the community. The authors develop and apply a methodology of isolating and measuring the effect of community risk factors such as building construction, occupancy characteristics, and sprinkler use. The total number of buildings in which the amount of damage is at risk are also considered.

Audience: Everyone.

Issue: Fire service effectiveness.

Policy Utility: This study is a must for those desiring to know the proper application of fire loss and hazard data. The study, written in 1943, is a classic.

Internal Validity: Impeccable.

External Validity: The methodology developed here could be applied to many studies of fire department effectiveness and productivity. (Some studies have failed because these methods were not correctly applied.) Questions of insurance rating, such as how sprinklers affect losses, are answered in this study.

Summary: This study is really an empirical extension of Measuring Municipal Activities, by Ridley and Simon (R4-6). In that work, it was stated that the ultimate measure of fire service effectiveness must be by looking at actual losses. The inherent risks also affect fire losses. The two effects must be separated. Simon et al. identify three sources of risk to investigate: occupancy (public, residential, mercantile, manufacturing, and miscellaneous categories), construction (fireproof, masonry or frame), and internal protection (sprinklered or not). Although other hazards exist, these are chosen for the ease with which the information can be collected and used. Losses are calculated as a percent of the value of the property in each of the 30 classes. Cities chosen for the analysis are Berkeley and Oakland. Data on value of buildings in each class are approximately by assessed values from the property tax records. The fire departments provide fire loss data. In Oakland, the necessary information on building type and value was scattered and required a tedious compilation. Berkeley's records, however, were centralized and easily to use. The authors suggest that all relevant building information be updated and kept in the assessor's files for all cities. The benefits of this information outweigh the expense of keeping a continuous inventory. When a fire occurs, building classifications should be cross-checked with the assessor's records.

The data collected for Oakland cover the years 1935-1940; for Berkeley, 1935-1939. Raw data collected for each of the 30 categories include total value of buildings, number of buildings, total fire losses, and number of fires. Ratios are computed as follows: fire loss per $1000 building valuation, (Tables 3-0 and 3-B) number of fires per 1,000 structures, number of fires per $1 million building value, average loss per fire, and percentage loss of contents to building.

When loss ratios are analyzed for each class, problems may arise. Using composite classes can be misleading for comparisons. In Oakland, unplaced frame structures have, unexpectedly, a lower loss ratio than sprinklered masonry structures. However, this is because of a greater preponderance of commercial uses for masonry structures, which accounts for the greater loss ratio in this structural class. However, looking at subclasses alone does not solve the problem since some of the subclasses have too few observations for reliable loss ratios. The authors resolve the difficulty by weighting the loss ratio in each subclass by the fraction of the total assessed value falling into that class and computing the weighted average. Using this method they found, for example, for all occupancies in Oakland (except dwellings) loss ratios of $0.46, $1.54 and $4.05 for fire resistant, masonry-walled, and frame structures.

The authors use ratios of fires per 10,000 structures in Oakland's residential buildings to test some hypothesizes about variability of fire rates. They test whether geographical location within Oakland (census tracts) shows differences in fire rates greater than what one would expect from chance variations. Chi-square statistics are used for these purposes. Linear regressions are performed using fire rates in one-family houses in census tracts as the dependent variable; age, year, rents, condition of structure, and density in the tract are the independent variables. Although results are not clear-cut, it is evident that geographical differences in fire rates between census tracts in Oakland cannot be explained by random variations alone.
Fire Losses and Fire Risks

TABLE 3-0

AVERAGE ANNUAL FIRE LOSS PER ONE THOUSAND DOLLARS BUILDING VALUATION
IN EACH CLASS, OAKLAND, 1935-1940

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<th>Occupancies</th>
<th>Fire-Resisting Structures</th>
<th>Masonry-Walled Structures</th>
<th>Wood-Frame Structures</th>
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<td>Dwellings</td>
<td></td>
<td></td>
<td>2.2413</td>
<td></td>
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<tr>
<td>Stores and Dwellings</td>
<td></td>
<td>.1351</td>
<td>.9710</td>
<td></td>
</tr>
<tr>
<td>Group Averages</td>
<td>.1351</td>
<td>.9710</td>
<td>7.8266</td>
<td></td>
</tr>
<tr>
<td>III. MERCANTILE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Office Bldgs.</td>
<td>.3328</td>
<td></td>
<td>.0541</td>
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</tr>
<tr>
<td>Small Retail Stores</td>
<td>5.576</td>
<td></td>
<td>.4398</td>
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<tr>
<td>Restaurant</td>
<td></td>
<td></td>
<td>2.9078</td>
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<tr>
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<td>2.2030</td>
<td>5.6007</td>
<td></td>
</tr>
<tr>
<td>Wholesale Houses</td>
<td></td>
<td>2.3152</td>
<td>.4953</td>
<td></td>
</tr>
<tr>
<td>Storage Warehouses</td>
<td>.0435</td>
<td>1.1025</td>
<td>.0063</td>
<td>.0653</td>
</tr>
<tr>
<td>Group Averages</td>
<td>.1021</td>
<td>.7340</td>
<td>.1351</td>
<td>.5745</td>
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<tr>
<td>IV. MANUFACTURING</td>
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<tr>
<td>Textile, Fabric Wks.</td>
<td>36.1043</td>
<td>.0659</td>
<td>.3973</td>
<td>.4621</td>
</tr>
<tr>
<td>Metal Workers</td>
<td>.1172</td>
<td></td>
<td>3.4885</td>
<td>.4988</td>
</tr>
<tr>
<td>Wood Workers</td>
<td>22.2074</td>
<td>1.4233</td>
<td>22.2327</td>
<td>17.6663</td>
</tr>
<tr>
<td>Food Products</td>
<td>31.9020</td>
<td>1.6818</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical Works</td>
<td></td>
<td></td>
<td>3.7153</td>
<td></td>
</tr>
<tr>
<td>Flammable, L. and Gases</td>
<td></td>
<td>.0257</td>
<td>2.6446</td>
<td></td>
</tr>
<tr>
<td>Multi. Occ. Mfg.</td>
<td></td>
<td>.0264</td>
<td>4.5885</td>
<td></td>
</tr>
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<td>Misc. Mfg.</td>
<td>2.202</td>
<td>4.5851</td>
<td>1.6809</td>
<td></td>
</tr>
<tr>
<td>Group Averages</td>
<td>.0961</td>
<td>1.8329</td>
<td>2.0490</td>
<td>2.3808</td>
</tr>
<tr>
<td>V. MISC. BLDGS.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lumber Yards</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ry. and Wharf Prop.</td>
<td></td>
<td></td>
<td>6.8636</td>
<td></td>
</tr>
<tr>
<td>Bulk Oil Storage</td>
<td>$0.0035</td>
<td>.5718</td>
<td>3.9411</td>
<td></td>
</tr>
<tr>
<td>Pub. Gar. and Fill. Sta.</td>
<td>.1315</td>
<td>1.5884</td>
<td>3.4973</td>
<td>1.6666</td>
</tr>
<tr>
<td>Misc. Structures</td>
<td>3.0974</td>
<td>6.6310</td>
<td>2.0224</td>
<td></td>
</tr>
<tr>
<td>Group Averages</td>
<td>.0983</td>
<td>.8929</td>
<td>2.0175</td>
<td>3.1616</td>
</tr>
<tr>
<td>Av.—All Occupancies</td>
<td>.1854</td>
<td>.4480</td>
<td>.4597</td>
<td>.6558</td>
</tr>
</tbody>
</table>
### Fire Losses in Oakland and Berkeley

#### TABLE 3-B

**Average Annual Fire Loss per One Thousand Dollars Building Valuation in Each Class, Berkeley, 1935-1939**

<table>
<thead>
<tr>
<th>Occupancies</th>
<th>Fire-Resistant Structures</th>
<th>Masonry-Walled Structures</th>
<th>Wood-Frame Structures</th>
<th>All Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sprinklerized</td>
<td>Unsprinklerized</td>
<td>Sprinklerized</td>
<td>Unsprinklerized</td>
</tr>
<tr>
<td>I. Public Bldgs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Government Bldgs.</td>
<td>$ .1133</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hospitals, etc.</td>
<td></td>
<td></td>
<td>$ .0973</td>
<td>$ .3874</td>
</tr>
<tr>
<td>Schools</td>
<td></td>
<td>$ .0117</td>
<td></td>
<td>$ .0885</td>
</tr>
<tr>
<td>Churches</td>
<td></td>
<td></td>
<td>$ 1.4269</td>
<td>$ .8277</td>
</tr>
<tr>
<td>Amusement Bldgs.</td>
<td></td>
<td></td>
<td>$ .0906</td>
<td></td>
</tr>
<tr>
<td>Group Averages</td>
<td>$ .0247</td>
<td>$ .0168</td>
<td>$ .3144</td>
<td>$ .0748</td>
</tr>
<tr>
<td>II. Residential</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hotels</td>
<td></td>
<td></td>
<td>$ .7020</td>
<td>$ .4333</td>
</tr>
<tr>
<td>Apartments</td>
<td></td>
<td>$ .5264</td>
<td></td>
<td>$ .4335</td>
</tr>
<tr>
<td>Dwellings</td>
<td></td>
<td></td>
<td>$ .3559</td>
<td></td>
</tr>
<tr>
<td>Stores and Dwellings</td>
<td></td>
<td></td>
<td>$ 1.6553</td>
<td>$ 1.0974</td>
</tr>
<tr>
<td>Group Averages</td>
<td></td>
<td></td>
<td>$ .4561</td>
<td>$ .3956</td>
</tr>
<tr>
<td>III. Mercantile</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Office Bldgs.</td>
<td>$ .0130</td>
<td>$ .0182</td>
<td>$ .0390</td>
<td>$ .0197</td>
</tr>
<tr>
<td>Small Retail Stores</td>
<td></td>
<td></td>
<td>$ .0935</td>
<td>$ .0738</td>
</tr>
<tr>
<td>Restaurants</td>
<td></td>
<td></td>
<td>$ 1.9371</td>
<td></td>
</tr>
<tr>
<td>Large Sing. Occ. Merc.</td>
<td></td>
<td></td>
<td>$ .7149</td>
<td></td>
</tr>
<tr>
<td>Malt. Occ. Merc.</td>
<td></td>
<td></td>
<td>$ .5367</td>
<td>$ .7763</td>
</tr>
<tr>
<td>Wholesale Houses</td>
<td></td>
<td></td>
<td>$ 1.2425</td>
<td></td>
</tr>
<tr>
<td>Storage Warehouses</td>
<td>$ 2.4611</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group Averages</td>
<td>$ .1522</td>
<td>$ .3521</td>
<td>$ 1.3495</td>
<td>$ .4973</td>
</tr>
<tr>
<td>IV. Manufacturing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Textile, Fabric Wks.</td>
<td></td>
<td>$ 3.9629</td>
<td></td>
<td>$ 1.5725</td>
</tr>
<tr>
<td>Metal Workers</td>
<td></td>
<td>$ .0025</td>
<td>$ .0347</td>
<td>$ .0131</td>
</tr>
<tr>
<td>Wood Workers</td>
<td></td>
<td></td>
<td>$ .5588</td>
<td>$ .0456</td>
</tr>
<tr>
<td>Food Products</td>
<td></td>
<td>$ .1307</td>
<td></td>
<td>$ .0947</td>
</tr>
<tr>
<td>Chemical Works</td>
<td></td>
<td></td>
<td>$ .3003</td>
<td>$ .0495</td>
</tr>
<tr>
<td>Flamm. Liz. &amp; Gases.</td>
<td></td>
<td></td>
<td>$ .1128</td>
<td>$ .0241</td>
</tr>
<tr>
<td>Mult. Occ. Mfg.</td>
<td></td>
<td></td>
<td>$ 8.7628</td>
<td></td>
</tr>
<tr>
<td>Misc. Mfg.</td>
<td></td>
<td></td>
<td>$ 3.0340</td>
<td>$ 2.1765</td>
</tr>
<tr>
<td>Group Averages</td>
<td></td>
<td>$ .4146</td>
<td>$ .4150</td>
<td>$ .3977</td>
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<tr>
<td>V. Misc. Bldgs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lumber Yards</td>
<td></td>
<td></td>
<td>$ .0948</td>
<td>$ .0952</td>
</tr>
<tr>
<td>Ry. &amp; Wharf Prop.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk Oil Storage</td>
<td>$ .0179</td>
<td></td>
<td></td>
<td>$ .0164</td>
</tr>
<tr>
<td>Pub. Gas. &amp; Fuel. Sta.</td>
<td>$ .0125</td>
<td></td>
<td></td>
<td>$ .0123</td>
</tr>
<tr>
<td>Misc. Structures</td>
<td></td>
<td></td>
<td>$ 76.7522</td>
<td>$ 15.1822</td>
</tr>
<tr>
<td>Group Averages</td>
<td>$ .0112</td>
<td>$ 23.7469</td>
<td>$ 5.5598</td>
<td></td>
</tr>
<tr>
<td>Av.-All Occupancies</td>
<td>$ .0441</td>
<td>$ .2176</td>
<td>$ .6231</td>
<td>$ .4788</td>
</tr>
</tbody>
</table>
**Discussion:** This study tells us how community risk factors affect losses, but it does not tell us how the service operations affect losses. However, it is the only study to date (and it was performed over 30 years ago) that relates fire losses to hazards for a small enough geographical area to be meaningful. This study is the how-to-do-it for anybody wishing to answer some of the following questions: How effective are sprinklers? (Only by holding other characteristics constant can this question be adequately answered.) How does construction type affect fire loss? Is the probability of a fire occurring the same for different construction or occupancy types? How good a predictor of expected damage is age of structure? Although the authors admittedly have a problem with too small a sample size, their data collection effort and analysis show the degree of care and detail that is needed in such studies. These are the kinds of procedures that the insurance industry should use in setting rates.

R4-2


**Abstract:** The papers deal with the problem of identifying cities that supply urban services more efficiently in order to transfer the techniques they have been using to other cities. To identify high productivity cities, costs have to be compared with effectiveness. The problem of measuring fire protection effectiveness is thoughtfully dealt with but not fully solved. Data for several cities are presented.

**Audience:** Everyone.

**Issues:** Can cities with high productivity be identified? Can this productivity be transferred?

**Policy Utility:** Potentially very high. The papers are a good beginning in the area of measuring and transferring fire protection productivity. Although many problems are left unsolved, the questions themselves are important. Other researchers could begin where these papers left off.

**Internal Validity:** Generally adequate, although a strong methodology is never developed.

**Summary and Discussion:** Fire protection productivity analysis relates the level of effectiveness (or output) to the amount of inputs. To use one of the authors’ examples of productivity:

If two cities, A and B, alike in fire-related characteristics (such as socioeconomic profiles, industry types, climate, and age of buildings) have the same rate of fires, but A devoted less manhours to prevention than B, we will consider A more productive in prevention than B. Similarly, if A had a lower fire rate than B, but both had similar resources devoted to fire prevention, we will again consider A more productive than B.

To measure productivity, we need at least three types of measures: output or effectiveness, inputs, and intrinsic "community" factors, for which we must control when comparing outputs and inputs. The authors add a fourth category—characteristics of fire department and water supply. They suggest examining the organizational differences reflected in this set of measures to try to explain differences in productivity observed between cities.

The authors separate fire protection into two distinct functions: fire prevention—to try to limit the extent of fire incidence—and fire suppression—to minimize the losses given that a fire occurs. Overall fire protection, the combination of prevention and suppression, is measured by the size of the demand for fire protection such as population, building value, etc., and the quality of the service—losses (averted), deaths, injuries, and the city’s insurance rating. Altogether, the authors discuss 27 output measures, 9 input measures, over 20 “community” characteristics, and 11 characteristics of fire department and water supply.

They suggest examining fire incidence rates to assess fire prevention output. Since many factors affect fire incidence besides prevention activities, this suggestion seems a bit simplistic. Suggestions for relating fire incidence and fire severity to time since last inspection are better.

Many measures of fire protection activities are given: property damage per fire, spread of damage, response time, insurance grade of fire department, death and injury rates, population served, property protected, citizens’ evaluations, calls per 1000 population, calls per company, percent of company time busy, miles of hose laid, feet of ladder raised, prevention inspections made, expenditures, manhours, climate and weather, area, population and density, land use, structural conditions, civil disturbances, the level of private fire protection, traffic and road conditions, socioeconomic conditions, number and type of vehicles, stations, companies, crew per vehicle, size of response to alarms, alarm and dispatch system, firemen per supervisor, special equipment, and grading of water supply.

The type of analysis that can be performed using the above output measures and data currently available is given in the form of plots of cities along two variables. Examples include annual fires per 1000 population versus population, full-time fire department employees per 1000 population versus population, fire service employees versus total fires, both per 1000 population, etc. Observing both trends and outliers is interesting, yet a better-defined methodology for analyzing specific aspects of fire protection would be helpful. The authors
advocate considering more than one measure of output and productivity. Yet, given so many measures and advice to use them two at a time, what to do is not clear. Suppose city A has fewer fires but more fire-fighters per 1000 population than city B. Then what? A firmer methodology should explicitly treat several variables at once, something the two way plots are not capable of. (Regression and analysis of variance are two likely candidates.) This multi-variable capability is essential if community characteristics are to be accounted for.

The authors could have been more critical of all three data sources: NFPA, insurance companies, and HEW. Insurance data, though probably quite reliable, are extremely difficult, if not impossible, to obtain for reasonable categories in many states. The NFPA data are collected and presented in less than a uniform fashion. HEW statistics are unreliable for purposes of comparing annual figures. Future sources of fire data at the national level are given as: Uniform Fire Incident Reporting System (UFIRS), the new National Fire Protection Association’s 901 reporting system, and the National Bureau of Standards’ National Fire Data Collection System. But the extent to which these systems will provide the data necessary for productivity comparisons was not directly assessed.

R4-3

Abstract: Ahlbrandt deals with the subject of provision of (generally accepted) "public services." Although it might be helpful or necessary for allocation to be provided at the public level, production of the service need not be. Two hypotheses are presented: production of such services could be less costly using competitive agencies rather than monopolistic bureaucracies; and output will thereby more closely meet the level desired by the community. A cost function of fire service is derived using regression analysis techniques on Washington state data. The cost function is applied to several municipal fire services in Arizona, as well as to the private company supplying Scottsdale. It indicates that the private firm is more efficient.

Audience: Economists, researchers.

Issues: Private vs. public production of fire protection, economies of scale.

Policy Utility: High, especially in describing some of the cost-cutting techniques employed in Scottsdale.

Internal Validity: The best of the economic literature we have seen. The cost function is nicely derived and applied, and results are explained well. But how can any hypothesis be proved on one observation?

External Validity: Scottsdale’s Rural-Metro Fire Department is not the only private fire service either in the United States or other countries. It would have been useful to examine others.

Summary: The dissertation is divided into chapters, each of which is interesting reading in itself, although the whole paper fits together nicely.

In the introduction, Ahlbrandt states, "The objective...is to examine the hypothesis that the competitive supply of fire services is more efficient than that of a bureaucratic monopoly." Also, the output supplied by a competitive producer will more closely follow the wishes of the community. Ahlbrandt argues his hypothesis using his basic beliefs in the market system and in free competition. He feels that a private producer will not be constrained by political boundaries and can produce at whatever scale is most efficient.

In the second chapter, the author develops an empirical cost function for testing his hypotheses. Various output measures can be and have been used. Ahlbrandt feels that one output measure alone cannot do justice to the cost function. Therefore, he chooses three quantitative measures: population, area, and assessed value of buildings. Qualitative measures include: fire insurance rating index (municipal grading) and numbers of ladders, fire stations, volunteers, fire stations, and full-time personnel. A wage index is included, as well as a variable indicating condition of buildings (percentage of housing units lacking all or some plumbing facilities). Total cost per capita is the dependent variable in the regression function. Although Ahlbrandt does not discuss why his particular functional form was chosen, one can see how useful it is in his discussion of the implications of the model and certain results. Although the results are to be used as a tool in the later testing of his hypothesis about private production, the author takes special care in discussing the implications of his results in terms of quantitative and qualitative output measures, factor prices, environmental factors, and economies of scale.

In all cases of testing for economies of scale, per capita cost of fire protection is the dependent variable. Ahlbrandt discusses economies of scale in terms of each of his quantitative output variables: population, area, and assessed value protected. By including quality measures, such as the insured grade and number of ladder companies, in his regression equations, he attempts to separate differences in the quality of service supplied from economies of scale in providing service.

The regressions verify two of his hypotheses: An increase in population, holding area and value constant, is associated with a decrease in per capita costs. And an increase in assessed value, a proxy for market value, is associated with an increase in per capita costs.

His third hypothesis, that an increase in area will result in higher per capita costs, is verified by regression for a fully paid department; but for mixed and for volunteer departments, such an increase in area results in lower per capita costs. For a simultaneous increase in all three quantitative output variables, constant returns to
scale are found for paid departments, and negative returns are found for mixed and volunteer departments. The observation points for the empirical work were 44 municipalities in the Seattle-King County, Washington area. The distinctions among paid, mixed, and volunteer departments were handled by using dummy variables, by themselves and in interaction with the three independent variables discussed above.

Chapter 3 begins with a description of the Arizona-based Rural-Metropolitan Fire Protection Company (R-M), a privately owned and operated but publicly regulated company. The company’s revenues derive 55 percent from individual subscribers and 45 percent from contractual arrangements with about nine jurisdictions, the community of Scottsdale among these. The organization of the company in Scottsdale is described. Besides fully paid employees and volunteers, there are “wranglers,” who are city employees doubling as part-time paid firemen. If they receive a call on portable bell paging units while at work, they must respond. Off-work hours, they may also be called. The wranglers are given several months of training as well as weekly training.

The Washington cost function is applied to Scottsdale and to five other Arizona cities. The difference between actual and predicted costs is computed and tested against a value of zero, using the t-distribution. All of the tests on the other cities show insignificant differences from zero. This means that the Washington cost function applies well to those cities with municipally operated departments. In Scottsdale, however, costs are actually significantly lower than predicted, showing that a private “competitive” company can provide service more efficiently.

Chapter 4 is a discussion of supply and demand differences under the two different types of fire service organization. Scottsdale’s service is thought to be more concerned with cost reduction and technological change. Some interesting factors of cost reductions are the wranglers, the R-M Company’s designing and building much of its own equipment, and the larger scale of operation allowed by ignoring political boundaries. On the demand side, Ahlbrandt feels that because of decreased political pressures and a greater awareness of costs to consumers, the preferences of the community are better met by the R-M company.

Discussion: In Chapter 3, Ahlbrandt states, “It is recognized that it may be spurious to generalize from a sample of one.” He believes that the conclusions are applicable to a wide spectrum of public services and to different types of political structures. We disagree. One observation is not good enough. Historically, and in other countries, other private fire services have existed and do exist. Why are none of these discussed? The R-M Company is not the only one in the United States today, but it is well-known perhaps because it is so well run and so open about its operations.

This does not mean that any fire chief could not learn from the operations of the R-M Company. The use of wranglers is especially applicable to municipal departments. The points about scale of operations might lead to some study of political organization of the department. It is not clear whether the R-M company is acting as a one or multi-plant firm in the specific scale discussion. But we don’t know, even after the study, how much of the efficiency is because the company is a private producer and how much is because it has an exceptional department.

Chapter 2, deriving and discussing the cost function, with special emphasis on volunteer vs. paid fire-fighters, is especially good. The issue of economies of scale is treated in an interesting and intelligent manner. Ahlbrandt achieves what Gardner (R4-5) fails to do in his paper. Although Will (R4-4) has a different approach to measuring economies of scale, the results on the effect of density (area), holding population constant, are consistent between the two papers. Ahlbrandt’s discussion of economies of scale with regard to three different output measures and three different types of departments (paid, mixed, or volunteer) goes beyond the ordinary methodology. Although separating growth effects into population and area is quite useful, we do not understand the utility of discussing simultaneous increases in all three quantitative output variables.

R4-4

Abstract: This paper takes meeting the insurance standards as its measure of required fire protection service. From grading reports for 38 cities, the number of men and pieces of apparatus needed to meet the standards is found. Then standard costs for men and equipment are used to compute a standard cost per capita for each city. This standard per capita cost turns out to be two to three times as large in small cities as in large ones.

Audience: Researchers.

Issue: Economies of scale.

Policy Utility: Some (if calculations were correct). The insurance standard for a city is not necessarily the economically justified level of protection. But the results would be useful for a study of the costs and benefits of regional consolidation.

Internal Validity: Generally adequate. However, the author mistakenly thought insurance standards require reserve fire apparatus to be manned while standing by. His calculations are therefore wrong.

R4-5
Abstract: In this paper the author develops a model showing the effects of income, wealth, and other community characteristics on expenditure levels for municipal services. The model is applied to data for 51 cities, using regression analysis. Fire service expenditure is one of the dependent variables used.

Audience: Economists.

Issue: Demand for and cost function of fire services.

Policy Utility: Low. This appears to be an intellectual exercise rather than a model of any real phenomena.

Internal Validity: Adequate. The model is very nicely worked through and presented.

External Validity: Inadequate.

Summary: The author assumes that through the voting procedure, the wishes of the median income voter are expressed at the municipal level. A utility function for the median income family is hypothesized. It is multiplicative in form, being a function of each of the municipal services provided, plus all other goods and services. The family budget constraint is expressed in terms of median income, nonmunicipal taxes, municipal taxes, and other expenditures. The cost function for municipal services is assumed to be linear, with level of service and an unspecified number of cost-function shifters as independent variables and cost per family as the dependent variable. An example of a shifter might be population, if there are economies or diseconomies of scale. It is also assumed that the service is distributed equally for all municipal citizens. Finally, it is assumed that the taxes are collected on income, net of federal and state taxes. Using all of these equations and the technique of LaGrange multipliers, Gardner maximizes the utility function of the family with the median income, substituting the sum of the cost functions for each of the municipal services for municipal taxes. After some manipulations, the author is satisfied that his equation is well applicable to a two-stage least-squares empirical test. In the first regression, average disposable private family income is estimated, then used as an independent variable in the second stage. Results for fire protection and total expenditures are presented in the following table. The average private family expenditures variables and the ratio of average to median family income were variables suggested by the model. Other variables were "shift" parameters chosen by the author. An extra variable, percent Irish, was added under the hypothesis that this particular ethnic group was in favor of, and had influence over, increases in local government expenditures on municipal services. A factor analysis procedure produced business and political leadership variables, which are not very well explained. Data sources, though, are given for each variable.

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Fire Expenditures</th>
<th>Total Operating Expenditures</th>
<th>Operating and Capital Expenditures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slope</td>
<td>t-Value</td>
<td>Slope</td>
</tr>
<tr>
<td>Average private family expenditures</td>
<td>15</td>
<td>2.5**</td>
<td>48</td>
</tr>
<tr>
<td>(thousands)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median education</td>
<td>-6.6</td>
<td>-2.0**</td>
<td>28</td>
</tr>
<tr>
<td>Average/median family income</td>
<td>-2.3</td>
<td>-.30</td>
<td>-.30</td>
</tr>
<tr>
<td>Taxable property per family (thousands)</td>
<td>1.6</td>
<td>2.7*</td>
<td>9.7</td>
</tr>
<tr>
<td>Manufacturing wage (hourly)</td>
<td>3.8</td>
<td>.61</td>
<td>18</td>
</tr>
<tr>
<td>Percent Irish</td>
<td>3.9</td>
<td>2.9*</td>
<td>5.5</td>
</tr>
<tr>
<td>Business leadership</td>
<td>-.7</td>
<td>-.70</td>
<td>-.21</td>
</tr>
<tr>
<td>Political leadership (x10^5)</td>
<td>-.96</td>
<td>-.35*</td>
<td>-.49</td>
</tr>
<tr>
<td>Density (thousands)</td>
<td>.32</td>
<td>.50</td>
<td>-.30</td>
</tr>
<tr>
<td>Population (thousands)</td>
<td>.079</td>
<td>1.6***</td>
<td>.22</td>
</tr>
<tr>
<td>Population squared (miles)</td>
<td>-.0000985</td>
<td>-1.5***</td>
<td>-.300</td>
</tr>
<tr>
<td>Constant</td>
<td>23</td>
<td>.71</td>
<td>-.65</td>
</tr>
</tbody>
</table>

* Significant at the 1 percent level.
** Significant at the 10 percent level.
*** Significant at the 20 percent level.
Discussion: There is no discussion of why the utility function is hypothesized as:

\[ U = a(x_1 - x_1)^a_1(x_2 - x_2)^a_2 \cdots (x_g - x_g)^a_g(x_m - z)^b. \]

The \( x_i \) are levels of each municipal service, the \( x_i \) and \( Z \) are defined by the author as constants, but he never explains what they represent. \( Z_m \) refers to private expenditures, and the \( a_i \) and \( b \) are "coefficients." Also, the implications of hypothesizing a linear municipal service cost function are not discussed, although it is known that it is easier to apply to a linear regression model. The municipal tax function, hypothesized as an income tax, is not the major form of municipal tax base, but rather property values are. It is not surprising, then, that taxable property per family is highly significant for both fire and police protection expenditures. (This is not true for all of the municipal services.)

The central assumption, that the tastes of the median income family determine municipal expenditures, is quite a strong one. The author does not discuss the implications of this assumption, nor does he discuss the other hypothesized functions. Neither does he discuss his results with respect to this hypothesis.

In discussing the regression results, Gardner concentrates on scale effects as indicated by the coefficient of the density variable. We do not think this approach is valid, since no attempt is made to separate the effects of demand on municipal service levels from the effects of city size on municipal service costs. That is, larger cities might have higher service costs because people living in larger cities prefer higher levels of service than people living in smaller cities. Economies of scale should not be a function of demand but strictly a function of costs of providing different levels of municipal services.

Although insignificant, the positive sign of the density coefficient for fire protection, holding population and all other variables constant, is contrary to most people's thinking on the subject. The author does not address possible problems of high correlations between independent variables; and given all of the reservations about the appropriateness of the model and possible data problems, we are not surprised at the results. But, perhaps density alone affects neither fire service demand nor costs.

Given the assumptions and original functions, the author meticulously works them into a form that can be used as a model for the two-stage least squares.

R4-6


Abstract: How can municipal services be measured so that the information can be of use to city managers? In this paper the authors give many thoughtful suggestions for deriving measures of effectiveness of fire protection (and other urban services).

Audience: City managers, fire professionals.

Issues: Measuring fire protection effectiveness.

Policy Utility: High. A must for fire officials still unconvinced of the need for and usefulness of good fire data.

Internal Validity: Good. The authors are thoughtful and thorough.

External Validity: The measures developed in this paper are applied in the Simon, Shephard, and Sharp paper (R4-1) and are generally applicable.

Summary: There are two uses of municipal service measurements: First, one can determine if the needs of the community are being adequately met; and second, if they are being met in the most efficient (least cost) way. Five kinds of measurements the authors deem useful are costs, effort, performance, results, and problem magnitude. Such information can help citizens critically evaluate their municipal government's performance, can aid the legislator in deciding where funds could best be spent, and gives the city manager feedback in performing his or her duties. Although there is no one correct level of service, once a decision is made on which level to choose, performance measures will aid the manager and others in evaluating whether the goals have been reached.

Ridley and Simon identify the final objective of fire service to be to minimize total fire losses and protection costs. Losses include losses to property and human casualties, indirect business losses, and premiums paid in excess of losses. On the cost side are costs of the municipal service, investments in private fire protection, and costs involved in compliance with fire codes.

Measurement standards then available were the NBFU Grading Schedule (especially for placement of companies), fire department expenditures, standards of effort and performance, and actual losses. The final judgment of fire service adequacy rests in actual losses. But comparing losses per capita or per $1000 valuation either between cities or through time presents problems, since several factors external to the fire service affect both the incidence and the severity of fires. Natural factors such as wind and coldness of climate affect use of mechanical heating devices, which may cause fires. The structural and occupancy conditions in a city affect fires. Moral hazards are the degree of care people exercise in preventing fires and the propensity to start fires purposefully (arson). Losses can be measured per valuation or per fire. Neither is a complete measure. The number of fires occurring per valuation or per building must also be considered.

Ridley and Simon suggest data that would be helpful in the future. They feel that it was impossible for them to measure efficiency of departments because of data
inadequacy. Measures comparable between cities had to be developed. The authors expressed hope that the new NFPA reporting standards then under development would help.

**Discussion:** The authors exhibit a great deal of common sense, a good deal of understanding of the problem in general, and a reasonable familiarity with fire service. Their discussion of external hazards affecting fire losses is especially good, and all of this is written in a very readable style.

The authors do not include a discussion of how to deal with the uncertainties that are more characteristic of police protection than of such services as libraries and recreation. Individual citizens are concerned with variance of losses as well as expected value. If individuals are risk averse, then expenditure on insurance premiums above actual losses is not necessarily money that has been spent inefficiently. Probably, also, fire officials prefer many small fires to a few very large ones.

R4-7


**Abstract:** "The purpose of this paper is to reexamine the degree to which municipal services are properly financed from (1) general purpose taxes . . . and (2) specific taxes, fees, and prices that attempt to reflect . . . costs and effects more closely." The concern with having payments relate more closely to costs and benefits is based to some extent on the desire for equity. But more important, the expectation is that such tax schemes will "increase the efficiency with which services are utilized, prevent waste, and in general improve the patterns along which our mushrooming metropolitan areas will grow." Vickrey uses fire protection as an example and finds that assessed value is a fair measure of the fire protection benefits received but that charges based on land area better reflect the cost of providing protection.

**Audience:** Mostly economists, but city managers could also benefit.

**Issue:** On what basis should fire services be taxed?

**Policy Utility:** Potentially useful, although the immediate utility is low. The paper fails to show how charges based on land area will improve efficiency. Also, before such charges were put into effect, it would be important to institute similar changes (if appropriate) for other services.

**Internal Validity:** Very good. The ideas are well and thoughtfully presented. The reasoning is sound.

R4-8


**Abstract:** The author wants to allocate fire benefits between commercial and residential buildings. He uses fire insurance premium reductions as his definition of benefits. The distribution of property taxes is then compared with the distribution of fire benefits for three cities.

**Audience:** Researchers.

**Issues:** Costs vs. benefits of fire service, pricing of fire service.

**Policy Utility:** Medium. More of long-range than short-range value.

**Internal Validity:** The proposed property tax does not necessarily give proper incentive to invest in private fire protection, contrary to Malko's discussion. The discussion of distribution costs and benefits is inadequate, but the empirical work is competently performed and all that could be expected given present data constraints.

**Summary:** Malko wishes to test whether the property tax is equitable in the following sense: He wants to examine "the extent to which the real property tax conforms to the benefits received rationale with respect to municipal fire services." He divides properties into two basic types: commercial and residential. He would like to measure benefits received as (the present insurance rate times the value of the properties) minus (the insurance rate if the city had no public fire service times the value of the properties) for each of the two property classes. Since the rate differentials were too difficult to measure, Malko instead used the total insurance premiums paid by each class to represent benefits from fire protection services. He applied his estimation procedure to Milwaukee, Washington, and New York.

When he totals the benefits for the two classes, he finds that in New York 55 percent of them go to commercial occupancies and 45 percent go to residences. When he totals the taxes, commercial occupancies pay 46 percent of them and residence owners pay 54 percent. Thus, in New York residential properties pay more than their share for fire protection in terms of benefits received. Similar numbers are found in Milwaukee and Washington. The property tax therefore does not accurately reflect benefits received from fire service. Since it does not reflect ability to pay either, it is an inequitable tax for fire service purposes. Malko suggests that the property tax base for fire service be adjusted to take benefits received into account.

**Discussion:** Malko suggests than an "adjusted" property tax base would provide incentives for building owners to supply better fire protection. To some extent, this is true. If a landlord wished to provide additional fire protection—a sprinkler system, for example—under the present tax system the building would probably be reassessed and his taxes and therefore fire service costs would increase. In most cases of the kind, Malko's
scheme would reduce taxes. But in any case where the insurance rating system did not accurately reflect fire risks, the tax would also be inefficient. Whatever efficiency and equity problems there now are in the rating system would be incorporated into Malko’s scheme.

Malko obviously thinks the distribution of fire service costs and benefits between commercial and residential properties is an important issue, yet he never tells the reader why he chose to address it. Fire protection is typically about 5 percent of a city’s budget, far smaller than police protection, for example. Is it worthwhile to reorganize the tax structure for such a small portion of the budget? See Vickrey (R4-7) for a fuller discussion of alternative tax schemes.

There are other ways of defining benefits. For example, in large urban areas, the depressed neighborhoods make the greatest demand on fire service and thus receive high benefits. These neighborhoods can least afford to pay for the fire service. Malko does not address this equity issue, or possible life safety issues. Given the known data problems, Malko competently performed his empirical study of distribution costs and the insurance benefits of fire service. But he did not adequately discuss benefits which his measure did not account for.

R4-9

Abstract: The paper discusses the potential advantages and disadvantages of tying fees for public fire protection services to property characteristics as a way of assigning costs for such services to beneficiaries on an individual basis. The tone of the paper suggests that it is directed at a general audience, but parts of it require minimal training in economic theory to appreciate fully.

Audience: Policy researchers primarily, not fire professionals.

Policy Utility: Potentially very high (because of the problem addressed); but actually low (because it is mostly armchair theorizing).

Internal Validity: Since it is a discussion paper, there is little to verify in the way of methodology. The reasoning in the text seems adequate.

Summary: After three pages of superfluous introduction, the argument gets under way with the section headed “Charging for Fire Protection: Possible Benefits.” The point is made there that fees for service would encourage users to consume only the right amount of services for them, thereby avoiding an overall excess of services by fire departments and misallocation of services across users. With this point, as throughout the paper, the author appeals—sometimes implicitly and sometimes explicitly—to standard notions of marginal cost pricing. He thus holds that individual and aggregate needs are serviced best when each individual consumes a given service or commodity up to the point at which the additional benefit to him of one more unit equals the cost of providing that unit, where cost includes all “social” costs.

Not to be caught advocating such clearly unreasonable policies as fire company turnout charges, the author next considers the inherent difficulties of defining a unit of fire protection and of deciding precisely what users should be charged for. He concludes that the best policy is a compulsory fee for comprehensive protection, on a yearly basis. This policy is, of course, what most communities have now, since fire department expenses are generally financed by local property taxes; but there is more to the argument yet.

He next spends several pages (i.e., sections headed “Fire Department Charges: Analysis” and “The Fire Protection System: A Simple Behavioral Model”) demonstrating that even if both the fire department and individual property owners are well intentioned and separately seek to behave optimally, they may fail to reach an optimal solution without fee-for-service pricing. In this context, behaving optimally is interpreted to mean seeking to maximize the expected value of damages averted less expenditures for fire protection. The “model” is highly abstract and might better be described as an illustrative example adapted from two-person game theory. (Economists will recognize it as a variant of the Cournot duopoly model.)

The paper continues with a discussion of possible pricing formulas. After much debate, the final recommendation is that the annual fee for a property should be determined on the basis of its assessed or fair market value, its total area, the number of people living on or otherwise using the property, a computed statistic representing the probability of fire on the property, and another statistic reflecting the resistiveness of the property to fire. Neither of the last two statistics is spelled out in detail, but it is argued that they could be readily computed by property inspections, once standard computational formulas had been adopted.

The alleged benefit of such a fee would be that owners would have an incentive to improve their properties to decrease the probability of fire and increase fire-resistiveness. A possible disbenefit would be that the fees would be regressive; that is, they would fall more heavily on low-income groups than on upper and middle-income groups.

Discussion: The paper makes some excellent points, but they all could have been said in fewer pages, and in much more readable prose, too. There is no empirical analysis and hence there are no quantitative findings.

The “model” is more clever than useful. Most people will agree that fire protection may reach a nonoptimal level of service with no fees. For those who need persuasion, this model will not help them much. Thus, the
model is either superfluous or ineffective, depending on one's view.

Since the paper is basically nontechnical, there is little to check in the areas of internal and external validity. All that can be said is that uncertainties are thoroughly covered and that the model is correctly interpreted, as far as it goes.

R4-10

Abstract: There are certain spillover effects of fire protection in a metropolitan area arising from the fact that people move across political borders. Building owners might live in a different political jurisdiction from that in which their buildings are located. People live and work in different areas. In this paper a methodology is developed that takes these factors into account and measures costs and benefits from fire service for the city and its suburbs.

Audience: Researchers.

Issue: Regional consolidation.

Policy Utility: Potentially high. Could be useful input to a study advocating regional consolidation.

Internal Validity: Good. Assumptions are explicitly and thoughtfully made.

External Validity: Results would be different under different assumptions, yet the methodology could be applied anywhere.

Summary: The authors develop a general methodology for measuring the distribution of benefits from fire protection in a metropolitan area. They then apply their methods to the Washington, D.C. area, and compute the dollar benefits to the city, suburban areas, and everywhere else. The underlying assumption used is that total benefits are exactly equal to total expenditures.

In the development of the methodology, the principles of welfare economics are applied thoughtfully. Assumptions necessary to the work are explicitly made, discussed, and defended. Three different methods are used to measure the benefits: (1) cost-of-service basis, (2) welfare basis (without any offsets), and (3) welfare basis (after offsets—if an increase in income occurs because of fire protection provided by D.C., this income will be subject to federal taxes; the federal taxes of this additional income are subtracted from the benefits). Besides distributing benefits across communities, benefits are divided between people and property on two different bases: 10 percent people/90 percent property or 50/50. For people, cost-of-service benefits accrue equally. On a welfare basis, benefits are a function of income. Residential and commercial properties are treated separately with benefits accruing to both owners and users on a thoughtfully chosen basis. Finally, total benefits to each of the metropolitan area communities are presented and compared with expenditures in each community.

The authors present their findings on benefits from fire protection obtained in many tables. The three different methods of calculating benefits and the two different assumptions about the division of benefits between property and people result in six different benefit figures calculated for each cell. The cells arise since there are three possible areas that provide benefits: Washington, D.C., suburban Maryland, and suburban Virginia. Also, the rest of the world is defined as a fourth recipient of benefits. Benefits for each of these cells are presented for each of eight income classes. The authors find that the measured benefits do not differ dramatically, whichever way they are calculated, for total benefits received. But the distribution of benefits among the eight income classes is quite sensitive to the method of computation. When total per capita benefits are compared with per capita expenditures for D.C., suburban Virginia, and suburban Maryland, D.C. accrues fewer benefits for what was spent, and suburban areas experience net gain.

Discussion: The authors desired to derive a meaningful and operational method for measuring benefits from fire protection. They achieve their goal without discussing why such a measurement system is desirable or useful. Even though the results may not have been directly useful, an introduction discussing the urban service measurement problem in general would have placed the study in some kind of perspective, explaining how such a study is useful. The authors do not present the broader aspects of this type of work. Given the distribution of costs and benefits in the Washington, D.C. area, another study might suggest different forms of financing protection when benefits flow across political boundaries in a metropolitan area but revenues do not.

Since the authors were only trying to develop a methodology of measurement, they used no statistical methods. The authors were thorough in their discussions of problems of the measurement process. They not only explicitly stated the assumptions but gave thoughtful reasons for their choices. When assumptions were made on a somewhat arbitrary basis, several methods were developed, so that the results could be compared for different assumptions. In discussing the results, they point to which figures were sensitive to assumptions or methods and which were not.

Although the authors state that their methods are designed to relate to the Washington, D.C. metropolitan area, they could easily be repeated for any type of metropolitan area. The thought and care that went into the methodological development were based on the desire to combine an economically meaningful measure with an operational one. This has been achieved.
R4-11

Abstract: The author proposes an accelerated depreciation allowance on state and federal taxes for building owners for private fire suppression features that are not required by building codes. Specific examples, such as sprinklers and fire doors, are given. The author explains that total tax revenues would actually not decline, since there would be fewer fire losses claimed.

Audience: Everyone.

Issue: Investments in private fire protection.

Policy Utility: High. Whether revenue would be lost remains to be proved. But given the inequitable and inefficient tax system we now have, this is still not an unreasonable proposal. And rewards for fire protection investments might bring a greater efficiency.

Internal Validity: Not applicable.

External Validity: An empirical study that outlines the effects of such a tax incentive is necessary.

R4-12

Abstract: The first part of this paper discusses practical aspects of evaluating the costs and benefits of proposed changes in a municipal fire protection system. Although ultimately intended to be more generally applicable, the discussion as presented depends heavily on data from Dayton, Ohio. A second section of the paper analyzes 1968 fire run data from Dayton. A third part describes a small simulation model of the Dayton Fire Department.

Audience: Fire professionals.

Issues: Can cost-benefit analysis be used in deciding how many fire companies to have? In other allocation decisions?

Policy Utility: Low. It would have been high if the authors had actually done what they said they would do.

Internal Validity: Weak in explaining and supporting methods and conclusions. Too little substance on benefits.

Summary: In several places, the introduction especially, the authors obscure the real content of the paper by misstating what it addresses and actually achieves. The substance is as follows.

In the first part of the paper, the authors start with the proposition that in seeking to minimize injuries, mortalities, and loss of property from fires, local governments face resource allocation problems that, to be properly resolved, require analysis of the incremental (marginal) costs and benefits of proposed improvements in their fire departments. Although on record as advocates of standard cost-benefit analysis, the authors do not concern themselves with conceptual problems of that approach, either in general or as applied to fire protection; nor do they even state what governments are supposed to do when they have the requisite data in hand. (The usual rule of accepting a project if marginal benefits exceed marginal costs may be criticized on a number of grounds. At the practical level on which this paper is dealing, though, it is generally regarded as better than any other workable alternative.)

The authors first consider three cost categories: manning, equipment, and fire stations. In each category, they calculate average and marginal costs from Dayton data. On manning, they compute an average cost of $200 per week for a typical fireman counting salary (base pay plus fringes), ancillary equipment, and administrative support overhead. They argue that the marginal cost of an additional man is just his salary. Assuming that new men would be hired at the lower end of the pay scale, they find a marginal cost of roughly $150 per week.

On equipment, they maintain that the marginal cost per week of an additional fire truck is its weekly value (a figure computed from its purchase price, its life expectancy, and an assumed interest rate) in such a way that weekly payments at the same constant level over its entire expected lifetime would sum to purchase price plus interest plus the marginal cost of the additional men needed to man the truck. To calculate average cost, they state that the total budget would have to be distributed over all pieces of equipment, weighted according to the number of men required for each and also by each original purchase price. As an example, they compute a marginal cost of $1880 per week for a $50,000 ladder truck. All but $80 of that cost is for manning.

On fire stations, the authors derive an average cost per year of $315,000 by dividing the total fire department budget by the number of stations. Assuming that 13 percent of this figure is overhead to which a new station would not add, they estimate a marginal cost per year of $270,000 (approximately 87 percent of $315,000). They also recognize the existence of other costs but present no data.

On the benefits side, the authors discuss difficulties in determining the dollar value of benefits. They make a few suggestions on method but do not actually compute estimates. They first argue that changes in insurance premiums should not be included in benefits calculations. Their reasons are entirely practical: Grading schedules are not updated often enough or in a way that permits close analysis of the effects of small system changes.

1 This could mean either total equipment budget, which would make the most sense, or total fire department budget. The authors are unclear.
changes. They then consider benefits in the form of reductions in the value of property losses, entering into an inconclusive discussion of the connection between loss and response time. Finally, noting that loss of life must also be taken into account, they recommend that a joint life-property loss index be developed and analyzed in conjunction with response rate.

Although the section on costs provides explicit estimates and guidelines for how to prepare them, the section on benefits is purely discursive. The reader is left with only half a road map to cost-benefit analysis, plus some discouraging warnings about dangers in the other half.

The second part of the paper analyzes 2,156 fire runs (responses to alarms) by the Dayton Fire Department in the last six months of 1968. On each run, the authors had data on the type of emergency (six categories, including false alarms), location within the city, time of alarm, duration of run, and several other variables. Their only conclusions are:

- Mean times between runs ranged from a low of 90.7 minutes during afternoon hours to 196.6 minutes during early morning hours. This marked difference suggests that the number of men on duty should vary with time of day.
- Roughly a quarter of all fire runs in Dayton (which has box alarms) are false alarms.

The final part of the paper discusses a small simulation model. Given data on the configuration of fire stations, equipment, and the risks of fires in zones of the city, the model apparently generates alarms, dispatches equipment, and computes equipment utilization. The authors stress that the model is still in a very preliminary stage of development.

**Discussion:** The authors seem to be unclear on exactly what they have to write about or at least are unable to communicate the logic of their ideas effectively. The section on costs suffers from too little development of basic concepts. The section on benefits lacks substance.

A number of calculations are incorrect by small amounts, as though they were only roughly computed. The procedure followed in annualizing capital expenditures on equipment is at best poorly explained and quite possibly is just wrong. The authors appeal to the language of depreciation when really they should be talking about depreciation. The procedure for estimating average costs for fire stations (and possibly also equipment, the text is unclear) will lead to double counting. At the very least, the authors should have discussed this.

Their conclusion that the number of men on duty should vary with time of day is not correct, since availability is not a problem. The low alarm rate means that simulation is probably not necessary. (See Chapter 10 of Part I of this report.)

A workable procedure for carrying out cost-benefit analysis would be of very high policy utility. The authors of this paper seem to promise that at the outset, but they do not accomplish it.

**R4-13**


**Abstract:** The purpose of this paper is to explain to the California city manager how the insurance grading process works, how it affects the city, and what the city manager can do to change his city's grading. The report explains how the grading schedule evolved, its principles, and how they affect the insurance premiums in his town. The authors use a hypothetical city, "Ourlville," to demonstrate the grading process and to explain each item in the schedule. On a quite simple level, the authors suggest a cost-benefit approach that the city manager should take toward improvements in the city's fire protection. Finally, there are suggestions on how to initiate a survey, how to request information about the survey, and how to interpret the results.

**Audience:** City managers; everyone.

**Issue:** What do you need to know about insurance grading?

**Policy Utility:** High. Any California city manager, and probably most city managers in most states, would find such a guide useful.

**Internal Validity:** Adequate.

**External Validity:** The study is generally applicable to cities throughout the country.

**R4-14**


**Abstract:** In this paper the authors translate insurance grading and rating schedules into lay terms and analyze how the schedules affect insurance rates under various methods. Methods differ from state to state, and the differences are discussed. In many respects, this report is similar to the earlier effort by the League of California Cities (R4-13). This report is broader since rating and grading methods are presented for all states except Texas. In California, the effects of a change in a city's grade on insurance premiums are clear cut. In other states, it is possible that an improvement in grade will have no effect on premiums. Managers are warned of this possibility and are given enough information to try to ascertain effects in their own towns.

The section on the grading schedule is quite similar to the one in the California report, although a "typical" city is not presented.

**Audience:** City managers; everyone.

**Issue:** Policy implications of standard insurance grading and rating policies.
Policy Utility: High. It is written and presented more clearly than the League of California Cities paper (R4-13).

Validity: Adequate. Since it is not an original research effort, there is no methodology to fault.

R4-15

Abstract: This paper surveys some of the problems facing fire insurance rate makers and proposes improvements to current methods. The author discusses statistical bases, residential vs. business classifications, expense ratios, credibility, term rule, deductibles, and coinsurance.

Audience: Actuaries and insurance people, but anyone somewhat familiar with the subject could understand this paper.

Issue: Fair rating for both insurers and insured.

Policy Utility: Moderate.

Internal Validity: Reasonable ideas, but no numbers are presented.

External Validity: This paper should be obsolete today, because of the extensive use of computers. Unfortunately, it is not different in method from papers currently being written on the subject.

Summary: The author begins with the assumption that the objective of rate makers is to create rates that are reasonable from the point of view of both the insurer and the insured. For the insurer, the sum of all premiums collected must be adequate to have reserve for catastrophes and to cover claims, expenses, and profits. For the insured, a reasonable rate covers the expected loss plus expenses, catastrophe reserve, and profits. Thus, a reasonable rate for the insured is more difficult to achieve but also assures a rate reasonable for the insurer. Rate making should not be so complex that its application is difficult and expensive.

There are basically three different insurance rating methods: the statistical system, where every rate has statistical support; the schematic system, "when the rating structure is complex, it is impractical to provide statistical support for each rate or rate differential and overall statistical support for groups of rates is all that is possible"; judgment rating, "when the factors which must be taken into account are so complex that a schematic system cannot be devised." It is important to note here that this article was written before the widespread use of computers, and complicated relationships had to be computed by hand. Longley-Cook poses the question of whether a statistical system is practicable for fire insurance.

He looks first at residential business. Since both the rates and bases are so low that individual inspections would not pay off, a number of features that might affect risk must be ignored. Construction and protection are the factors that should be considered. The author suggests standardizing the subcategories for residential buildings on a national basis, rather than the existing system of having a different method in each state under the local NBFU.

For other than residential risks, a statistical system is not deemed feasible, although standardization of base rates could be achieved in a manner similar to the class rates for residential buildings. The author is not very clear about how to handle the rate differentials for the various hazard factors.

The rate maker should exercise great care in making rates based on experience alone. One catastrophe could produce high rates for a particular class for a long time. The author suggests allocating part of the premium to catastrophe losses and basing the rest on experience. The way this is to be done is not really explained because "an experienced rate maker should be able to deal with the problem without setting up special arrangements of this nature."

Other specific suggestions for changing rates are:
- The expense ratio should be allowed to vary according to size of policy, classification, and territory. The rating schedule should be changed to account only for risks. Then expenses, profits, and catastrophes could be added on.
- According to the term rule arrangements, a three-year policy was granted for $1200 premium and a five-year policy for $800 of premiums, paid in advance. Longley-Cook feels that this 20 percent discount is not justified for large risks. It would be too disruptive to the companies to abolish the term rule; instead, discounts should be given according to the size of the premium.
- Deductibles and coinsurance problems can be solved only by studying adequate loss distribution curves for major classifications.

Discussion: The author does point very thoughtfully to areas of problems in rate making. And his explanation of the different types of rate making is useful. He claims that rate makers prefer the system that uses the most statistics. The author argues his points in terms of putting more statistics and less judgment into rate making practices, although he does not have real numbers or situations at hand. The fact that he is discouraged from going any further into the statistical approach because of the complexities involved is understandable in the precomputer era. But, unfortunately, the same paper could be written today by someone in the casualty actuarial business. See, for example, Brockmeier (R4-18), published in 1972.

Longley-Cook contends that there is not "sufficiently reliable" data to eliminate the judgment factor from fire insurance rate making. However, he presents no data to support this claim.
R4-16

Abstract: This paper attempts, by example, to show how the loss experience for several classes of risks can be used to set a rate for a class with no experience. It is necessary that each hazard in the new class be present in at least one of the classes for which experience is available. The idea is to associate rates with hazards and so leads to a rationale for the fire insurance rate schedule.

Audience: Everyone.

Issues: Do the schedules fairly reflect the risks? Is the system capable of equitably distinguishing sprinklered from nonsprinklered risks, etc.?

Policy Utility: If the answers are negative, then changes to ensure equity may affect the protection that property owners will find economic and thus influence what the fire department will (or ought to) do.

Internal Validity: Weak. The paper is characterized by inadequate definition of concepts, fuzzy reasoning, and avoiding the problem.

External Validity: Neither real rates nor real loss experience are provided, so there is no way to judge it.

Summary and Discussion: A simple example is given where all the properties to be insured are divided into four classes of risks. There are four different fire hazards. One hazard is present in all properties, the second is present in all but class 1 properties, the third in all but classes 2 and 4, and the fourth in all but classes 3 and 4. The author shows how loss experience for these four classes can be used to determine a rate for a property that does not fall in any of the classes—for example, one with hazards 1 and 3 present. This is done by associating rates with hazards.

In getting this far, you have to wade through notions of probable loss and probability of loss that are inadequate in several ways. The most important is that there is no time notion; it ought to be the probability of a loss in a particular year or month, for example. This lack leads to some fuzzy reasoning about statistical independence and mutually exclusive events.

The second example has three classes and six hazards. It has some hazards present only in a fraction of the properties of a particular class; for example, the second hazard is present in all class 1 properties, no class 2 properties, and some class 3 properties. (Before it was all or nothing.) Even when the fractions are known, the author shows that there is no unique way of associating rates with hazards. But why were there only three classes of risks? Why would not the loss experience be collected for six (or more) classes in a situation like this? (His justification that there may be dozens of hazards is weak even for 1960. Computers could handle the algebra then.) The likely real reasons for not having lots of risk classes—the problem of too few properties in each class to yield statistically reliable loss experience—is not mentioned.

A second paper does not rectify the inadequacies.

R4-17

Abstract: The author of this paper gives the following illustration of the kind of problem he wants to solve: Consider fire insurance rates for small brick dwellings. There is "reliable" loss experience on all small dwellings and on all brick dwellings, but there is not enough experience on dwellings that are both small and brick. How do we set the rate?

Audience: Underwriters, state insurance regulators.

Issue: Is it possible to set a fair rate for a small group of risks?

Policy Utility: Low. An interesting issue, but badly handled.

Internal Validity: Weak. The author invents his own technique instead of using available statistical theory (linear regression, analysis of variance). Basic concepts, such as reliability, are not defined. A central problem—how to construct the groups—is never addressed.

External Validity: Inadequate. No real data are examined to validate the approach. The book by Simon, Shephard, and Sharp (R4-1) did it better—using real data and developing statistical theory—a generation before this paper.

Summary and Discussion: Bailey begins his paper with a definition of the rate making problem. A class (he does not define this term) of risk might provide insufficient (also not defined) data on premiums and losses to give "a reliable basis for the rate for that class." The present solution is to set a rate for each class on the basis of judgment. Then all of the rates are adjusted by a uniform percentage to produce proper total premiums for all risks within a general category. Classes within one category can be grouped into several subdivisions. An example is given: The class is small brick dwellings, the subdivisions are small amounts of insurance and brick dwellings, and the category is dwellings. (Although definitions are not given, at least one can get an idea of what the author has in mind by his example.)

There is a tradeoff between bias and reliability in the rates. "When we combine all classes to produce a single adjustment for all classes, the sample mean is unbiased and the resulting adjustment is unbiased in the aggregate, but none of us believes that the resulting rates are unbiased for each class. . . . The more we can subdivide the data, the less biased are the resulting rates for each
Abstract: The author of this paper defines the "residual markets" as all of the risks that are considered unprofitable by the insurance companies and therefore cannot obtain insurance. Insurance rating methods should be revised so that poorer risks pay higher rates but can obtain insurance. Brockmeier presents several general suggestions for revising rating procedures.

Audience: Insurance professionals or others with a basic understanding of fire insurance.

Issue: Fire insurance rating.

Policy Utility: Moderate—too general to be high.

Validity: The author's suggestions are sensible.

Summary and Discussion: The author lists four types of residual markets:
1. Entire lines of insurance deemed undesirable—e.g., professional liability.
2. Entire classes within a line—e.g., fire insurance for supermarkets.
3. In a normally acceptable classification, the risks that remain after the better risks have been taken.
4. Individual risk with poor loss experience.

The paper deals with the first three types of residuals. For the residual risks under study, Brockmeier states that it is really a philosophical issue whether the need for insurance should become a right. Yet, in practice, this is solved through the political process: "Blessed is he who goes unnoticed when Washington taketh away, but is up front when the goodies are passed around" (p. 4).

Market restrictions exist because the rating system is inadequate. A. F. Dean established the analytic system of rating (used throughout the midwest) at the beginning of the 20th century. Building conditions have changed since then, and so have data-handling facilities, yet insurance rating methods have not. The author calls for an objective a posteriori (based on statistical experience) rather than a subjective a priori (based on judgment) of risk probability) rating system. Four obvious examples of inadequacy of the present rating system are presented.

Suggested changes in the rating system are made:
1. There should be a nationwide system of classification on data collection rather than the present statewide method.
2. Code number of the classification should be assigned in a standard form, leaving no room for insurance clerks' judgments.
3. The basis for the rates should be responsive to ten-year revolving experience.
4. Applying rate deviations from norms should be allowed based initially on judgment. This would help eliminate the exclusion of bad risks from the market.
5. Statistics should be collected to see if age affects loss probability for residential class-rated structures, and if it does, it should be applied to the rate.
6. Consideration should be given to publishing pure loss rates.
R4-19

Abstract: The authors of this paper collected approximately five years of loss data on 9,500 retail stores across the country. It included information on value, losses from various property perils, and whether or not the building was sprinklered. They "analyzed" losses with respect to location, exposure, construction, public protection, private protection, water flow alarm, and maximum losses possible.

Audience: Researchers, people familiar with fire insurance.

Issue: Rating—does real loss experience support current rating practices?

Policy Utility: Potentially high, but low because of validity.

Internal Validity: Inadequate. Their statistical procedures are not equal to the task of assessing the effects of property characteristics on losses. They treat the factors separately (rather than in combination) and so might be associating effects on losses with the wrong factors.

Summary: Following 40 pages of introductory text (an explanation of risk management, probability functions and loss functions, and property insurance rating) the authors come to their empirical work. National chain or franchise stores were chosen for the analysis, although the sampling procedures are not detailed. Most of the stores were either variety or full-line department stores. Comparing their sample with the 1967 Census of Business Information, the authors find that more than 18 percent of the variety and department stores in the country fall within their sample of 9,400 retail units. Information from 1965 to 1970 concerning construction category, value of the inventory, whether or not the structure was sprinklered, location, municipal grading level, and exposures were gathered for most of the sample. Property losses due to crime, fire, extended coverage, and other perils were compiled. A pure loss rate was defined as the dollar value of the losses divided by the dollar value of the inventory. Pure loss rates are calculated for each value of inventory classification and for sprinklered and nonsprinklered buildings; tables are presented showing the total number of stores, the number of losses, value of inventory, and value of losses.

Then the authors try to ascertain whether construction, exposure, grading class, location, sprinkler protection, or loss frequency affects loss ratio. Their results are presented below.

Discussion: The source of data and the data collected are quite good for the type of study desired, even though the results would be for a single specific occupancy class. Since specific loss information is hard to come by, this data set is quite valuable.

Unfortunately, the methodology used is inappropriate and invalidates the study. When one studies the effect of one factor, say grading, on fire losses, other factors must not be allowed to vary or results can be spurious. For example, consider the slight effect of frame construction in unsprinklered risks. The effect of construction by itself might be large, but be compensated for by (say) the provision of more fire companies in cities where it predominates.

It is possible to handle several factors at once. Simon, Shephard, and Sharp (R4-1) encountered this problem 30 years before Allen and Duvall. They solved the problem first using a weighting technique, then by a multiple regression procedure. These computations were very difficult 30 years ago because electronic computers did not exist, but they are now easy.

EFFECTS OF VARIOUS FACTORS UPON LOSSES
(from Table 63 in book)

<table>
<thead>
<tr>
<th>Fire Insurance</th>
<th>Sprinklered Risks</th>
<th>Unsprinklered Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBFU class of the city</td>
<td>Slight effect</td>
<td>None</td>
</tr>
<tr>
<td>Construction</td>
<td>None except for frame</td>
<td>Slight</td>
</tr>
<tr>
<td>Value of inventory at risk</td>
<td>Slight</td>
<td>Slight</td>
</tr>
<tr>
<td>Location of risk</td>
<td>Very slight</td>
<td>Slight</td>
</tr>
<tr>
<td>Rating of the exposure hazard</td>
<td>Significant</td>
<td>None</td>
</tr>
</tbody>
</table>

R4-20

Abstract: This paper examines the property-liability insurance industry from an economic point of view, analyzing prices, sales volume, market concentration, and a number of other factors that determine or characterize the insurance market and its sellers (the insurance companies). The analysis is organized into three main divisions: (1) structure of the industry, (2) development of governmental regulatory policy and the pricing behavior of the market, and (3) performance of the industry. The paper concludes that open competition will reduce premiums and increase the supply of insurance. Specific recommendations are made for state governments to reform regulation.

Audience: Policy researchers, state legislatures, insurance regulatory agencies, and others concerned with the details of insurance regulatory reform. Parts of the article are accessible only to those familiar with economic theory.
Issues: What is the nature and effect of governmental regulation of the insurance industry? What are the relative merits of the two main insurance marketing mechanisms, the American Agency System and direct underwriters?

Policy Utility: Very high. An important problem is carefully analyzed and feasible recommendations that promise much improvement are made.

Internal Validity: Very good. Clear, sound reasoning is used throughout. Simple but illustrative mathematics is used where appropriate. Qualitative logic and a concise but thorough review of the industry's history are effectively employed.

External Validity: Good. A wide range of alternative sources is used for comparison or analysis, and the author has shown consistency across all of them on his main points.

Summary: Concentration ratios, number of firms entering the market, and an analysis of scale economies (shown to be constant) are examined and show that the market structure is close to the perfectly competitive ideal. A review of the development of governmental regulation precedes an analysis of pricing behavior. The goal of regulation over the years has been quite consistently directed at preventing destructive competition (i.e., competition that forces firms into bankruptcy) and maintaining adequate profits. It has been attained, and Joskow's analysis shows that prices have not been competitive (except in states that have open-competition insurance laws, a recent phenomenon in most). Finally, the performance of the market is assessed in terms of: (1) production technology, taken as sales technique of which there are two major types; (2) supply shortages, evidenced by the federally authorized FAIR plans and the growing share of the insurance market taken by nonvoluntary, subsidized pools; and (3) profitability and capacity utilization taken, respectively, as return on assets and the premium-to-equity ratio. The performance analysis explains the behavior of direct insurance writers (pricing just below rating service levels used by agency-marketed firms, selective creaming of high-profit, low-risk customers, and unexpected slowness of growth caused by limited equity capital). It indicates that direct writing offers substantial saving to the consumer. Among other conclusions, the author recommends deregulation of insurance rates, freedom to establish homogeneous rating classifications, and a combined role for state insurance departments to provide information for consumers and monitor firms' solvency, marketing practices, and payoff policy.

Discussion: This is a very high-quality article and a must for anyone examining the fire insurance industry. It is unusually broad and deep in its analysis. The author has the habit of presenting definitional accounting equations in odd forms, and the reader is warned. The regression results are clearly presented and interpreted. Two possible flaws may exist. The first is that the author has not evaluated the validity of the data supplied by the industry (mainly through Best's Aggregates and Averages, an annual report). The accounting practices of the industry are known to be obscure. Perhaps the author has examined this and decided it is not a problem, but in this constantly growing industry it seems possible to make current losses seem high every year, while pyramiding profits into the future indefinitely. Second, more attention could have been paid to the implications of the underwriting losses and investment profits that have characterized the industry. (For example, the industry showed underwriting losses in seven of the ten years 1963-1972, and an overall underwriting loss for the whole period, while investment income was large, positive, and growing.) Perhaps they operate like banks and not only can but must pay money (underwriting losses) to borrow capital (what Joskow calls "unearned premium income" or what is known more generally as "the float" in monetary dealings). Joskow touches on this in assessing the industry's profitability and in constructing the economic, behavioral models examined. However, he does not explicitly consider the influence this will have on firms' behavior. For example, firms have every incentive to delay payoffs for damages since their income is derived from investing the float. Since firms are insensitive to modest underwriting losses, they have little incentive to improve their marketing efficiency (which may explain the durability of the agency system: If firms stand to gain little by improved marketing efficiency, why challenge existing law that protects agencies and risk incurring the wrath of agency trade associations?)

All in all, this is a fine and important article as far as it goes; but, as its author acknowledges, more data and more research are necessary. Additionally, a broader look at the incentives faced by insurance firms would be valuable.

R4-21

Abstract: This paper describes the problems dealing with the state of fire insurance in the inner core of major metropolitan areas. Fire insurance plays a significant role in the economic health of inner-city neighborhoods because most financial institutions require a property to be covered by insurance before they will lend its owner any money. In recent years, inner-city property owners have had great difficulty in obtaining insurance coverage. After the civil disorders of the mid-1960s exacerbated the problem, federal legislation was introduced; while it has expanded the availability of insurance, coverage is still costly or unobtainable for many inner-city property owners. The sources of the problem lie in the decay
of the inner city and the refusal of the insurance industry to adapt its methods to the changing urban environment.

**Audience:** Everyone.

**Issues:** The provision of fire insurance in the inner city.

**Policy Utility:** A useful discussion of the problem.

**Summary:** For the past two decades, fire and property insurance have grown increasingly difficult to obtain in the inner-city areas of most major American cities, including New York. This lack of insurance has important social and economic consequences, since most financial institutions require that a property be covered by insurance before they will grant a loan to the property owner attempting to use the property as collateral. Thus, a lack of insurance in an area stymies efforts to maintain or improve an area.

The insurance market problem was exacerbated by the civil disorders of the mid-1960s, and as insurers appeared ready to abandon inner core areas entirely, the federal government introduced FAIR (Fair Access to Insurance Requirements) plans in 1968 to make insurance more available. The FAIR plans created state pools, owned by the insurance companies, that would insure properties meeting minimum standards of insurability but unable to obtain coverage in the open market. The New York FAIR plan has grown at a phenomenal rate, but its insurance coverage has proved to be far more costly than private insurance and is plagued with administrative problems.

The basic sources of the insurance market problem lie in the deteriorating conditions of the inner city combined with the archaic methods of the insurance industry, which underlie insurers’ inability or unwillingness to respond to a changing environment by adapting rates and coverage.

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**R4-22**


**Abstract:** The book begins with brief chapters on fire insurance companies, underwriting, construction, occupancy, exposure, and public protection. Then, it starts its main task, dealing with sprinklers. Topics discussed include how to inspect sprinklered occupancies and how to investigate fire losses in them, the performance record of installed sprinkler systems, and sprinkler leakage. It relies on National Fire Protection Association, *Fire Protection Handbook* (13th ed.), Boston, 1969.

**Audience:** “This book is . . . primarily for . . . those . . . in the Special Risk inspection operations of the Fire Insurance Rating Organizations” (from the book’s preface).

**Issue:** How are insurance rates for sprinklered risks set?

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**Policy Utility:** Indicates that much needs to be done in looking at alternative ways of classifying sprinkler protected property at risk in fire.

**Internal and External Validity:** There is no way to assess the book’s validity. For example, the author indicates the need for “trained judgment” and “accurate and up-to-date information on the critical factors” (p. 72). But what constitutes trained judgment and how it is acquired are not clear. And precisely what information is needed is also not clear.

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**R4-23**


**Abstract:** This paper interprets the provision of fire protection services in economists’ terms and proposes a procedure that local governments could follow to determine the optimal level of services. The idea is to compare the costs of attaining different ISO grades with the reduction in insurance rates.

**Audience:** Researchers.

**Issue:** How should local government decide how much fire protection to provide?

**Policy Utility:** The idea of comparing the benefits of an improved ISO grade with the costs of attaining that grade is obvious and practical.

**Internal Validity:** Weak. A simple idea is embedded in a great deal of extraneous economic theory. The author does not discuss the weaknesses of his method. The insurance grade may be a poor measure of the fire protection provided. If so, the quantity of fire protection provided could be far from “optimal.”

**Summary:** Readers of this paper are likely to think at first that it is purely a taxonomic exercise, with no other aim than to restate conventional notions about fire protection in the language of economics. But the author does have a substantive argument. His case is buried at times in the inexorable defining of terms, but it does finally get spelled out in full near the end of the paper (in the section headed "Efficiency Conditions"). The argument concerns the criteria a government should follow in determining the optimal level of fire department expenditures.

If the government were a profit-maximizing firm with an easily measurable product to sell, its decision rule would be simple: Produce the level of output at which marginal cost equals marginal revenue. But the matter is not this straightforward. Fire protection services are not an easily measurable product, the government does not sell such services to individual consumers in a market, and it is not a typical profit-maximizer. Thus a different decision rule is needed. Pickett proposes this rule: Adjust the scale of fire department operations to the
point at which the marginal cost of further improvements equals the marginal benefits. In other words, the standard cost-benefit concept is applied to the fire department as a whole. Apparently regarding this rule as obviously reasonable, he does not justify it or discuss possible conceptual or theoretical difficulties (which is unfortunate, since it does need motivation and there are some difficulties).

His rule eliminates the market-based features of the profit-maximizing rule, but it leaves him with other problems. He must devise a means of measuring benefits and he still needs a measure of output.

He argues that the government should first find out the grade given to the area within its jurisdiction by the National Bureau of Fire Underwriters. (This is now done by the Insurance Services Office.) This grade, he maintains, indicates the quality of its fire department.

Since grade one is best and grade ten is worst, he proposes that the government should determine its equivalent grade on a reverse scale (e.g., a one becomes a ten, a two becomes a nine, etc.) The resulting number is to be treated as a measure of its fire department's output. (The purpose of this conversion is apparently just to be able to have rising numbers mean a higher level of output).

From the NBFU grading report, the government has detailed information on the deficiencies in its fire department with which it can compute the dollar cost of alternative sets of improvements that would raise its output one, two, and more points, up to the maximum ten level. After performing these calculations, it selects the least-cost combinations of improvements for achieving each successively higher output level. This selection yields a schedule of marginal costs similar to a private firm's marginal cost curve for different production levels. The final step is to divide the cost figures by the number of protection units in the municipality. A protection unit is defined as $1,000 of insurable property. The division eliminates the money dimension from the cost figures and leaves them in protection unit terms.

Now the government has estimates of marginal costs of increasing output. For estimates of marginal benefits, it should consult tables of fire insurance rates. Rates per protection unit are available for each NBFU grade. The decline in the insurance rate that results from increasing output by one point, the author argues, is a reasonable measure of the marginal benefit of that increase. Since marginal costs and marginal benefits obtained in this manner are both in protection unit terms, they can be compared directly. If each is a well-behaved function with respect to variation in output along the ten-point scale, the optimal level can be chosen straightforwardly. The author presents a hypothetical example to illustrate how his procedure works. The result, not surprisingly, is that it works like a charm.

Apart from this main argument, the paper makes a number of minor points, only one of which is important enough to note here. That point is on the relation between the amount of insurance individual property owners buy and the scale of fire department services. Individual property owners cannot affect the scale of services; only the government can do that. However, scale of services can affect the insurance purchases of property owners in two ways. First, a low level of services will induce risk-averting owners to buy a lot of insurance; and, conversely, a high level of services will lead to smaller insurance purchases. Second, the rates at which owners can buy insurance depend on services through the NBFU grading scheme.

Discussion: Though the author asserts that the NBFU grades indicate fire department quality, these grades depend in part on attributes of the municipality that are not within the fire department's control. Does this mean the grades are no good for output measures? Or perhaps they are all the better for this reason. He does not say. There are some scheduling ambiguities inherent in his plan for finding least-cost combinations. For example, improvement A might be less costly than B or C if the goal is to increase output by one point. But if the goal is to increase output two points, the least cost route may be first to do B and then C. None of this is mentioned. Nor does he discuss what happens when the marginal cost and marginal benefits functions are not well-behaved.

Most important, the proposed scheme rests on the accuracy of the insurance grade in measuring fire protection. If the grade is a poor measure, the so-called "optimal" quantity may be far from the true optimal. Although examining the costs and benefits of an improved grade may be the best that an individual city can do, the overall effect could be inequitable and inefficient.

R4-24
J. R. Morris, Jr., Urban Service Costs and Substandard Housing in Denver, Chapters I-IV, Denver Urban Observatory, Denver, Colorado, May 1973; also in NTIS PB223500.

Abstract: The paper analyzes six urban services in Denver, fire service among these, to see how costs might change if substandard housing were eliminated. With a linear regression model, the result for fire service is that probably no reduction in cost would occur.

Audience: Researchers.

Issue: Distribution and indicators of fire costs within a city.

Policy Utility: If valid, moderate for the city manager.

Internal and External Validity: Results are not fully presented and therefore cannot be verified. His definition of capacity is inappropriate.

Summary: The Denver Fire Department currently allocates costs of operation on a geographical basis. Insurance standards (ISO) are used for company placement so that, in residential areas, engine companies cover areas
approximately 1-1/2 miles in radius and ladders cover areas about 2-1/2 miles in radius. Morris notes that the busiest company worked only 567 hours out of the 8,760 hours in a year. He concludes (incorrectly) from this that excess capacity exists and the present placement of companies is more than adequate. He argues that excess capacity implies that the marginal cost of extra fires is close to zero. Although Morris' implicit definition of "capacity" is wrong, it is probably true that increased demand has close to a zero marginal cost.

But if costs were allocated on a demand (call or alarm) basis, then the effect of substandard housing could be compared with other variables that might affect demand. Linear regression is used to find the relationship between demand in a census tract and the tract's characteristics. The characteristics used as independent variables include population density, land area, percentage of substandard housing, percentage of poor population, mean house age, percentage "Anglo," percentage of population aged 0-14 years, and percentage of population aged 15-24 years. Several different measures of demand are used: residential fire vehicle minutes of service, home-related alarms minutes of service, vehicle minutes of service for all calls, number of residential fires, number of home-related calls, total number of alarms. In a second set of linear regressions, the substandard housing variable is replaced with the percent of housing condemned. Both of the substandard housing variables are significant (at t-test 5 percent significance level) when total number of alarms is the dependent variable. This result implies that the existence of substandard housing is associated with the number of total calls, but not the incidence or severity of residential fires.

Population density and area are generally significant in the regressions, usually with positive signs. Percent poor is strongly positively significant in all regressions. Mean house age is always insignificant. The two population age categories are usually insignificant but have negative signs.

Discussion: Morris discusses his regression results in a manner that is impossible to follow since he does not give the complete results in his tables. His hypothesized function has an intercept, yet he does not provide intercept results. Therefore, the reader cannot be sure whether his interpretations on the elasticities of the dependent variable with respect to each of the independent variables is correct. Also, he does not tell the reader how many observations (census tracts) he has, nor why he chose a 10 percent sample of fire calls to provide averages for each of the census tracts. Nor does the reader get any notions on the actual range of values of the dependent variable.

The author's notion of excess capacity is inappropriate. Fire companies could be almost always available yet response times could be poor and additional companies needed.

The author claims that he eliminated the percent "Anglo" variable because "it was too colinear with the income variable." He does not present a correlation table for independent variables, and we do not know what the threshold correlation value is to eliminate a variable. If percent poor and percent substandard housing have a high positive correlation, this could wash out the results of trying to separate the effects on fire of housing and poverty.

Given all of these reservations about the validity of the regressions, the results are quite interesting. He did not find an association between substandard housing and the incidence or severity of residential fires.

R4-25

Abstract: This paper addresses the question of deciding whether to install sprinklers and early detection devices in municipal buildings, based upon comparison of cost and insurance savings.

Issue: The economics of installing fire protection devices.

Audience: City administrators, fire professionals, researchers.

Policy Utility: High, although marred somewhat by the methodology.

Internal Validity: The methodology could be improved.

External Validity: Generally applicable.

Summary: For each building, three factors are considered: life hazard, property damage potential, and strategic value—i.e., the effects of a fire loss on town services. For each factor, there are high, medium, and low levels of risk. Corresponding to each of the nine factor-risk combinations is a specified return on investment (ROI) (for example, if life hazard = high, ROI = 1 percent). For each building a required ROI is determined by taking the minimum of the ROIs corresponding to each factor.

The cost of complete installation of sprinklers and its effect on insurance premiums is then estimated and an actual return on investment calculated. If the actual ROI is less than the required ROI, sprinklers are not installed. A determination is then made whether to install a detector and alarm system. Here the decision rule is, install a detection system if the cost of the system is less than X percent of the maximum foreseeable loss, where X depends on life hazard and strategic value.

Discussion: In this paper a generally sensible approach is presented to an important problem. However, it appears to us that associating a numerical ROI with each of the nine factor-risk combinations is a useless
procedure. The decision to install sprinklers depends on four measures: (1) insurance savings in dollars, (2) life hazard, (3) property damage potential, and (4) strategic importance. Only the first is a quantitative measure. The others should be treated qualitatively. Converting them to quantitative measures is a purely subjective and unjustifiable step. The folly of this method is illustrated by the fact that the calculated ROI for the high school is below the required ROI of 1 percent. This would normally mean a decision not to install sprinklers. However, the authors decide to recommend sprinklers anyway.

R4-26

Abstract: "A method for quantitatively evaluating costs, not from an economist's point of view but as an engineering analysis, is described and an example of applying the method is given." In this paper the method compares fire protection costs per $100 value protected with fire losses per $100 value protected. These two ratios are compared for one building with the average for a sample of buildings.

Audience: Everyone.

Issue: Investments in private fire protection.

Policy Utility: Moderate. A thought-provoking paper.

Internal Validity: Fair. Does not discuss data adequately, although the author is more interested in presenting the methodology.

R4-27

Abstract: The purpose of the paper is to guide the architect and engineer, in building design, toward a sensible and thorough approach to fire protection. The designer should work with an insurance consultant who is familiar with the rating schedule, but should ultimately make the final decisions, weighing the importance of the rate reductions. When computing rate reductions against protection systems costs, interest, maintenance, and additional taxes should be included as well as depreciation.

Audience: Everyone.

Issue: The costs and benefits of investments in private fire protection.

Policy Utility: Potentially high, but does not provide any specific guide.

Internal Validity: The author's approach is sensible, but no solid methodology is developed.

External Validity: Although many would agree with Winquist, further studies need to be done.

R4-28

Abstract: A decision analysis procedure is developed for evaluating investment decisions for fire protection at airports: whether to install sprinklers and how much insurance to buy.

Audience: Engineers, fire professionals.

Issues: Private investments in fire protection.

Policy Utility: Low, because of lack of validity.

Internal Validity: Many very specific and unbelievable assumptions are made with no substantiation.

External Validity: The applicability to real situations has not been demonstrated.

Summary: The purpose of the study is to apply a decision analysis procedure to the problem of choosing levels of fire protection at airport facilities. There are two basic choices to be made by the airport planner: the amount of physical protection (sprinklers, hydrants, etc.) and the amount of insurance. A decision about physical protection has an associated loss function. Adding information about the insurance decision also has an associated cost function. Since property owners tend to be risk-averse, the utility function of the owner is dependent on the levels of risk associated with each strategy as well as the expected losses.

The authors state that the airport decisionmaker will make the best choice by minimizing the total disutility involved in paying for any fire protection strategy, allowing levels of physical protection and insurance to vary. By specifying the three functions—loss, cost, and utility—the authors can make the best choices for different airports. Using 33 observations over a ten-year period, the authors specify a complex probability distribution of loss for sprinklered structures. They do not derive their distribution. Losses of unsprinklered structures are given but were "developed" elsewhere. Costs are obtained "from industry sources." A risk utility function is assumed for property owners that the authors feel is "reasonable in light of previous experience." For specific owners, the authors think they could measure the exact amount of risk-averseness by using a "carefully structured mathematical questionnaire that can be applied within an hour" and is "accurate and reliable."

There are two possibilities the authors allow for physical protection: sprinklers or no sprinklers. Costs are associated with each of these two strategies. Eight levels of insurance are given, with associated costs. The probability that a fire occurs is given as .273 in all instances, but this figure is not explained. And expected monetary losses are derived from the damage function, given in the text, and the amount to be reimbursed by the insurance company. Then, the "certainty monetary
equivalent" of the disutility of each expected loss plus the (variance) risk involved is given based on the assumed utility function. The authors find that for a $55 million airport facility, no sprinklers and $100,000 deductible insurance is the best choice.

**Discussion:** We are expected to believe a complex loss function that is based on 33 observations but not explained. This function is the basis for the results, yet nowhere do the authors admit that this is a mathematical formula that is only an approximation of the actual occurrences. They assume that property owners are constantly risk-averse. This does seem reasonable. But specifying the exact utility function is not. They use data and figures, as previously mentioned, that are not explained or presented.

Because of the total reliance on specific functional forms, the results or methods could not be applied elsewhere.

An interesting quirk in the fire insurance schedules is revealed, which could be of use. Otherwise, the study is not useful.

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**R5-1**


**Abstract:** The Bureau of Community Environmental Management ran a three-year pilot-demonstration project in the Bootheel Area of Missouri (six counties in the southeast corner of the state) to determine if an education program could significantly reduce burn injuries. This document is a how-to manual intended for local public officials to use as a guideline in implementing similar programs in their own areas. The effort had two parts: (1) creating an epidemiological data gathering system, and (2) involving the public and informing them of the problem and remedial actions. During the first 1-1/2 years of the project, the main emphasis was on developing the data system. Then most of the effort went into the education-involved effort.

**Audience:** Everyone.

**Issue:** The effectiveness of fire prevention education programs.

**Policy Utility:** Potentially high but marred by questions of internal validity.

**Internal Validity:** Weak.

**Summary:** In 1964, the Statistical Department of the Missouri Division of Health prepared a set of maps for the ten-year period 1954-1963, showing deaths by falls, fires, firearms, poisonings, and drownings for each county. In a contiguous six-county area in the southeast corner of the state, fire death rates were two to five times higher than the national and state annual averages of 4.3 and 4.8 per 100,000 population. There were no apparent reasons for these high rates. The counties in question looked much like other counties in Missouri. Apparently, however, fire protection was poor with few paid departments.

The study sought to answer two questions:

1. Why did these counties have fire death rates two to five times higher than in other areas of Missouri with comparable socioeconomic population factors?

2. How could these deaths be prevented?

In November 1966, the project recruited a field coordinator and three field representatives, each representative to cover a two-county area. The development of a nonfatal burn injury reporting system was established to obtain base line data on the magnitude of the burn injury problem and to provide necessary information for conducting epidemiologic investigations on the specific injuries. The field representatives conducted a series of home interviews with burn victims. A statistical summary of data collected through epidemiologic field investigations of reported burn injuries in the six-county area from January 1, 1967 to March 31, 1968 was made available in July 1968. They found a disproportionate number of nonwhites being burned (84 percent of the population were white, but only 61 percent of burn victims were white); a somewhat higher rate of injuries in cities; the most common sources of injury were stoves, hot grease, and hot water; 28 percent of injuries happened in the kitchen, 30 percent in the living room.

The major emphasis during the first year and a half was on the epidemiologic phase, although "some educational activity was initiated." Apparently, this refers to information given to those people interviewed.

As soon as the statistical evaluation was complete, a comprehensive community action program was begun in the project area to reduce or prevent burn injuries. This effort included setting up burn injury councils as conduits of information to clubs and organizations. Demonstrations were given using models, slides, etc. Near the end of the project, a health department communiqué was developed incorporating the findings of the project and putting forth suggestions for the prevention of burn injuries in the home. The communiqué was mailed to approximately 140,000 residents.

**Discussion:** The fire death rate from 1954-1963 in the six counties was 15.7 per 100,000 per year. From 1964-1966, it was 12.9 and from 1967-1969 it was 7.4. The difference in the last two figures is a reduction of 43 percent, attributed by the authors largely to the program. Further, the foreword to the report states that an evaluation made two years after the conclusion of the project showed that in 1970 deaths were 80 percent lower than the average rate from 1954-1963.

Unfortunately the authors do not give any of the actual death statistics by year. It looks as if deaths were well on the way down when the project began (15.7 per 100,000 from 1954-1963, 12.9 per 100,000 from 1964-
1966). They compare these figures with the average for 1967-1969 but, again, do not give the yearly figures. There is little indication that the program was responsible for the reduction in deaths. They admit that the education part did not really start until the middle of the three-year period. Also, they do not look at the causes of death before and after the start of the program. Were some types of fires eliminated? Could education conceivably have been a factor in reducing the incidence of those fires? Were the death rates reduced in all counties? Also, what happened to burn injuries? They don’t say. Also, there was no control group for the study. The education effort was carried out across the board.

This paper has been cited in America Burning (National Commission on Fire Prevention and Control, 1973) as an example of how fire prevention education works. Given its lack of internal validity, the best one can say is that the paper indicates education might work.

R5-2


Abstract: In this paper an analysis of statistics on fire-related deaths and injuries in Robeson County, North Carolina from 1957 to 1961 revealed that the problem was most acute among nonwhite children under ten years of age. An adult education program was instituted. Data were collected on hospital admissions of non-white children under ten for nine-month periods before and after the program, revealing a 65 percent reduction in incidence (from 17 to 6).

Audience: Everyone.

Issue: The effectiveness of fire prevention education.

Policy Utility: Low.

Internal Validity: Questionable. The approach here is the same as that used in the other prevention studies reviewed (R5-1, R5-2). It is not well documented.

R5-4


Abstract: The paper assesses and analyzes available data regarding arson and false alarms by youths in San Diego. Principal recommendations: (1) improve data base to facilitate evaluation of (2) a large-scale experimental education and prevention program aimed at seventh and eighth graders.

Audience: Fire safety and educational personnel in fire departments, schools, and youth agencies, social and fire researchers.

Issue: The extent, causes, and prevention of juvenile arson and false alarms.

Policy Utility: Some; the methods could be applied elsewhere.

Internal Validity: The data analyzed in the paper are not a representative sample of arson and false alarm incidents involving juveniles, as the author carefully notes. Therefore, the observed relationships are only suggestive. The hypotheses are sensible and there is healthy recognition of the need for good baseline data prior to testing of experimental programs.

External Validity: The methodology and recommendations are generalizable. The specific patterns uncovered required further testing, both in San Diego and elsewhere.

Summary:

Highlights of Data Analysis (based on sample of 200 juveniles):

- **Sex**—over 90 percent of participants were boys.
- **Number**—most incidents involved either one child (38 percent) or two children (32 percent); very few involved a large group (less than 9 percent of incidents involved five or more youths).
- **Age**—small cluster of children involved in fires around age 7; large cluster around age 13 involved in both arson and false alarms.
- **Grade in school**—involvement in incidents increases with grade from grade five through grade nine, then rapidly declines.
Family structure—62 percent were living with both parents, 30 percent with one parent, 7 percent with a parent and a step-parent.

Month—incidents most frequent in the period January through May; least frequent in July and August.

Day of week—incidents rise to peak on Tuesdays and Wednesdays, then decline to a low on Saturdays and Sundays.

Time of day—erratic. Peaks at 8 a.m., 12 noon, 2 p.m.

Location of incidents—60 percent of the fires were set in schools or on school grounds; 58 percent of false alarms were in or near schools.

Social Background of Older Youths (based on sub-sample of 50 cases)

Residence—80 percent lived in San Diego for over three years.

Home situation—25 percent had a recent “family crisis” (e.g., father lost job, parents divorced).

School—most had average or below average grades; 35 percent frequently late or absent; 60 percent had some social adjustment problem according to school counselors.

Contact with juvenile authorities—7 percent had contact due to custody proceedings; 18 percent due to criminal behavior such as burglary, larceny, and auto theft.

Recommendations:

1. Develop better data by (a) encouraging better communication among fire, education, and probation systems; (b) urging fire personnel to fill out juvenile contact sheets as completely as possible; (c) developing improved fire incident reporting, including “identification of fires and false alarms where no one was apprehended but that were probably caused by youths.”

2. Utilize the existing and future data to evaluate the effects of a large-scale experiment in fire prevention education. This experiment would focus on the entire 7th and 8th grades of eight junior high schools representing several distinct socioeconomic and ethnic communities. The experiment would test four distinct approaches: (a) Multi-Media Program (“essentially slide presentations, similar to collages, geared into a narration/dialogue”); (b) Movie Presentation Program (fire safety documentary films with lectures and discussions); (c) a Junior Fire Marshal Program (to delegate school fire prevention responsibilities to students, “and thus ‘co-opt’ them from being problems into becoming real assets”); and (d) Adult Sensitization and Education Program (aimed at school faculty, administrators, and maintenance staff).

Discussion: The data comprise an admittedly nonrandom sample of Fire Department records of arson and false alarm incidents in which juveniles were apprehended. The sample was chosen partly on the basis of record-completeness, which the author warns is associated with more serious incidents and with older children. Moreover, the universe of such Fire Department records, being limited to incidents in which someone was apprehended, is likely to be biased toward school-related incidents (as shown by the dip in incidents in the summer) and also badly undercounts incidents involving minority youth (because of low apprehension rates, which the author reports are due to poor community relations).

R6-1

Abstract: This paper reports a study of 24 fatal and high-damage fires that occurred in tall buildings between 1950 and 1968. The factors observed to contribute to danger are discussed, and recommendations are made for improving safety.

Audience: Fire professionals, code writers.

Issue: What factors affect high-rise fire safety?

Policy Utility: High, for all decisionmakers.

Internal Validity: Statements regarding factors and recommendations appear generally to be valid.

External Validity: Actual fires were studied.

Summary: A study was made of 24 fatal and high-damage fires in buildings six or more stories high, throughout the world between 1950 and 1968, to determine factors contributing to death, fire spread, and smoke spread. A total of 99 persons died in six of the fires. Differences between old and recent buildings were considered (e.g., in old buildings fire spread through stairwells, in new buildings smoke spread through stairwells). The findings were (numbers in parentheses show number of fires in which factor occurred):

Vertical fire paths (14): Windows (5), stairs or escalators (4), shafts (4), refuse chute (1). Compartmentation, both vertical and horizontal, can control this.

Smoke spread (16): Smoke and toxic fumes may be greatest danger. Material (nonstructural) control may be effective. The chimney effect is important in high buildings; these are a function of height, temperature, and airtightness. The paths along which smoke spread were stairs (4), shafts (8), airhandling equipment (4).

Basement fires (7): Smoke acts as a barrier to access; basement fires are often unobserved because of their location.

Elevators: Controlled use is needed for firemen and occupants. In two of three cases of malfunction, the elevator went to the fire floor.

Escape: Egress requirements by codes are inadequate for rapid evacuation in tall buildings. Communication: Space must be maintained both for operations of the fire brigade and to reassure occupants to avoid panic.

Recommendations are made as follows:
Smoke spread control: Pressurize stairways or provide ventilated lobbies; seal shafts at each floor; provide
smoke detectors to control air handling systems; provide smoke ventilation for basements.

Refuge places: Divide occupancy space into compartments, each connected to stairs and elevators.

Elevators: Some are to be assigned for firemen's use exclusively, with manual override.

Emergency power: Should be provided for fans and elevators (codes require only lighting and exit signs).

Communications: Use two-way intercom and public address.

Windows: Restrict size and combustible ceiling finish nearby.

Discussion: Reasonable statements are made regarding factors contributing to observed effects in actual high-rise building fires, and reasonable recommendations made to overcome them. No mention is made of sprinklers. The statement of need for two-way communications is weakly supported though probably correct.

Actual fires were studied. With the lack of correlation between tests and real fire hazard, this is in a sense the only truly valid type of study.

R6-2

Abstract: Smoke as a factor in building fires is discussed in this paper. Several standard tests are presented and their comparability, or lack thereof, discussed. General requirements for smoke tests and their validity are formulated. Conclusions: Different standard tests are not comparable to each other, and results are not relatable to real fire conditions.

Audience: Architects, code-writers, researchers.

Issue: Are smoke test results meaningful for real fire situations?

Policy Utility: Medium for city managers, high for persons concerned with codes and specifications of building furnishings and construction materials.

Internal Validity: Material is consistent with the limited definition of smoke used in this paper.

External Validity: The paper itself warns that test results may not be relevant to actual fires.

Summary: The paper is about smoke products of combustion consisting of particulate matter, chiefly unburned carbon and suspended liquids. It does not consider toxic gases and heat production.

A number of studies of smoke tests, fire studies, and test burns are referred to. Some materials produce more smoke when smoldering, others when flaming. In most tests, visibility was lost and irritant (eye and throat) concentration became intolerable before other dangers (e.g., high temperature, toxicity) arose. Under such conditions, exits cannot be found and occupants would be immobile unless rescued. A series of plastic tests are summarized in terms of the smoke density factor (SDF, defined in ASTM standard E84-68):

1. SDF to 16: good visibility
2. SDF up to 200: up to 6 minutes before visibility reduction
3. SDF over 350: fair to obscure visibility.

Building regulations are discussed. Most that regulate smoke production are arbitrary. Some require materials to be no worse than a specified material. Unless the test method is specified, however, the reference materials can yield much or little smoke depending upon ventilation, heat source, space volume, etc. Some base smoke restrictions on flame spread, which is generally unrelated to smoke.

A brief discussion of methods of controlling smoke flow in buildings follows. The several smoke tests are described:

1. ASTM E-84 25 ft. tunnel test
2. ASTM E-286 8 ft. tunnel test
3. ASTM D-2843 smoke chamber test
4. ASTM E-162 radiant panel test
5. Monsanto test method
6. NBS smoke chamber.

All except the tunnel tests use small samples; all measure smoke density; only the NBS test has been used for gas analysis, but all could be.

A general discussion of test criteria refers to:

1. Type of test: "go, no go" vs. numerical range, the latter being more useful for specifications and design.
2. Reproducibility and repeatability: Intralaboratory and interlaboratory tests have been made for methods 1, 3, and 6, with generally satisfactory results (after revisions for method 1) for each method alone. Because of the differences in characteristics for each test, no correlation has been possible among the methods.
3. Relation to hazard in building fires: At the present time, there is no firm basis for relating test results to fire hazard, so specifications are arbitrary.
4. Size and cost of apparatus: The tunnel tests, usually referred to in codes, require expensive equipment. Consequently, there are few installations, and shipping, travel, and test delays.

Even if the specification problem for smoke production were solved, there still remain the problems of fuel load from furniture generally being capable of producing more smoke than building materials, and of the total hazard of combustion products including toxic substances, heat, and oxygen deprivation.

Discussion: The summaries of studies of fires and test burns are authentic and well-selected. The various smoke measurement tests are accurately described. As the paper states, however, such test results are not currently directly relatable to smoke production in actual fires.
No hypotheses are formulated, but the material presented is relevant to the limited definition of smoke. One atypical result of a study indicating high temperature of the smoke as the chief danger is stated without commenting on its contradiction by other references.

The actual relative danger from smoke, as narrowly defined here, compared with toxicity, heat, and oxygen insufficiency is not clear.

R6-3

Abstract: The author discusses the flow of air and smoke caused by pressure differences between the inside and the outside of tall buildings. The differences are due to the stack effect. Equations are presented relating to the location of the neutral pressure plane, below which air flows into the buildings and above it flows out. Effects of wind, shafts, and wall openings on air and smoke flow are also discussed.

Audience: Architects, engineers, fire-fighters, researchers.

Issue: The control of smoke movement in tall buildings.

Policy Utility: High for designers of buildings and equipment. Has the beginning of the treatment of smoke concentration over time. But a long way from predicting when smoke concentration in different parts of a building will disable occupants.

Internal Validity: Appears adequate, although no derivations of equations are presented.

External Validity: Smoke problems are primary in high-rise building fires, and the conditions involved here are generally applicable. However, no real or experimental fire data are compared with either the flow pattern illustrated or the predictive model results.

Summary: Smoke-caused asphyxiation and poisoning resulted in more deaths in fires than did burn. Smoke reduces visibility, preventing escape by occupants and hindering fire-fighting.

Smoke and normal atmosphere behave about the same except in the immediate vicinity of the fire. Pressure differences caused by wind, fans, and high temperatures at the fire cause spread of smoke, but the chief cause of smoke spread is normal air flow, which is produced by temperature-induced pressure differences between the inside and the outside of the building.

Except in explosions, the pressure difference is small compared with the absolute pressure, so that volume varies with the absolute temperature. A table relates pressure difference to column height of hot (fire-temperature) air, column height of warm air, wind speed, and air flow through a door crack.

With ambient air colder than that in a building, the pressure inside the building will be lower at the lower floors and higher at the upper floors than pressure on the outside. Air leakage will be inward at the bottom, outward near the top. At an intermediate floor around mid-height, pressure will be the same inside and out—this is the neutral pressure plane (NPP)—and no flow will occur here. The formula \[ h_2/h_1 = A_1/A_2 \sqrt{T_2/T_1} \] is given, where \( h_2 \) is distance from NPP to top of building, \( h_1 \) is distance from ground level to NPP, \( A_1 \) is the open flow area at the bottom (inlet) and \( A_2 \) the top (outlet), and \( T \) and \( T_2 \) are the absolute temperatures of air inside and outside the building.

Wind pressure differences \( \Delta P \) are related to the wind velocity \( v \) and air density \( \rho \) by \( \Delta P = \rho v^2 / 2 \). External pressure is about this much higher at wind side, and lower by 0.5 and 0.7 times this amount on the leeward side. The NPP will therefore tilt from the level, and be at different floors in different parts of the building.

Actual tests have shown leakage between adjacent floors to exceed leakage in or out of the building on a single story.

The normal pattern of air flow within a building will be upward leakage from floor to floor. Leakage from outside into the building and then into any top-vented shaft will occur on floors below the NPP; leakage from shafts into floors and then outside the building will occur on floors above the NPP. If the outside air is warmer, these effects are reversed.

A fire on a lower floor will cause smoke flow into the shaft and into floors above the NPP.

The fire-fighters' practice of venting at high floors will reduce smoke concentration at the fire but increase burning rate and, "hence destroy the building much more rapidly unless fire-fighting is successful."

Top-vented shafts raise the NPP, so that a fire on an upper floor might cause smoke to enter the shaft, whereas a lower NPP would cause the smoke to flow out of the building.

Openings will change the flow. For example, open windows on a fire floor low in the building will cause increased smoke flow into the shaft and also lower the NPP, thus causing smoke flow into floors that would otherwise have been below the NPP.

Some results of analytical study of time for smoke to travel from floor to floor are given for leakage in an otherwise sealed hypothetical building, but they are of little use.

Discussion: The results presented are important in the study of smoke movement in tall buildings, but one could wish for somewhat clearer explanations. Understanding is also hampered because the scales of the pressure diagrams, a very important part of the paper, are not labeled, even as to direction of increase.

R6-4

Abstract: The authors discuss smoke movement in tall buildings and present the means for controlling the
spread of smoke and its concentration. Use and effect of shafts, vestibules, and mechanical air-handling equipment are discussed, and their effects on pressure distribution are presented based upon digital computer results.

**Audience:** Fire-fighters, architects, engineers.

**Issue:** How to control the movement and concentration of smoke in tall buildings.

**Policy Utility:** High for fire-fighters and building designers.

**Internal Validity:** No original ideas or new research to challenge here, but references cited are authoritative.

**External Validity:** The smoke problem in high-rise building fires is generally considered the most severe, and conditions discussed are present in all high-rise fires.

**Summary:** After brief mention of some problems of fire in tall buildings, the paper confines itself to smoke, its movement, and control. The requirement for smoke control is stated as follows:

Because of the time required to evacuate occupants and the tendency for smoke to flow upwards through a building, high buildings shall be designed so that, in the event of a fire, the levels of smoke concentration in specified regions can be maintained within values that can be tolerated by occupants for an indefinite period. The specified regions shall include stairwells, at least one elevator shaft, and floor spaces readily accessible to all occupants and large enough to accommodate them.

A smoke level of 0.01 times the maximum level in the fire area is recommended, requiring 100:1 dilution with clean air for any leakage from the fire to the safe areas.

Smoke movement is caused by the same agents as air movement: stack action, wind action, and mechanical air-handling equipment.

Stack action results from pressure differences caused by temperature differences inside and outside the building. In cold weather, inside pressure is lower; this results in air flow into the building and shafts at the bottom and out of the building at the top. Such air flow is due to leakage, even if all nominal paths are closed. The pressure difference diminishes on the upper floors and reverses direction above the "neutral plane," ordinarily near the mid-height of the building.

Results of digital computer calculations are presented showing pressure-height profiles outside, on floors, and in shafts under a variety of conditions. For example, with a fire on a lower floor, opening a window will increase the smoke travel to shafts, such as stairways; with a fire on an upper floor, flow of smoke will go to the outside.

Wind action tends to make air flow through the building horizontally in the windward and out the leeward side, but vertical flow can sometimes be induced.

Mechanical air handling effects depend upon balance of supply and exhaust air. Design and operation can be such as to aid fire safety under emergency conditions, by having excess supply (pressurizing) or excess exhaust.

High temperatures caused by the fire will cause some localized stack effects, but these are generally not important. More important is the resulting increase in volume, as great as threefold, which creates large pressure differences that force smoke into all adjacent spaces.

Smoke level control can be accomplished by dilution (injecting smoke-free air) or by limiting smoke movement to the safe areas by controlling building air pressures and restricting leakage openings. Venting of the fire zone to the outside to relieve pressure buildup is generally desirable. Venting methods include panels in exterior walls and smoke shafts terminating above the roof that are open to the fire floor and closed to all other floors; but the former can increase smoke spread to upper floors by stack action if the fire is on a lower floor, and the latter can be negated by opening of windows on the fire floor.

Smoke spread by vertical shafts can be prevented by isolating the shafts from the buildings with heavily ventilated vestibules, by separating buildings into two halves to prevent smoke travel horizontally from the fire to the safe half, or by pressurizing shafts to prevent smoke from entering those in which smoke cannot be tolerated. Top vents or exhaust fans can be used in shafts that can tolerate smoke.

Injection of air into all levels can pressurize the building and prevent smoke spread when the fire floor is vented to the outside.

Stair and elevator shafts can also be protected from smoke by providing entrance through vestibules that are either vented to the outside at all levels or are pressurized.

**Discussion:** Explanations of the observed, calculated, and anticipated pressure differences are usually lacking, but the material presented is very useful. The dilemma of whether to ventilate a fire (smoke removal vs. higher combustion rate) is unresolved here, as everywhere else.

R6-5

**Abstract:** Arguments are presented in this paper in favor of attempting to evacuate high-rise buildings, based on selected fire cases and the behavior of people. The author concludes that elevators are the best means for evacuation, and they should be designed for reliable operation during fires.

**Audience:** Fire-fighters, architects, engineers.

**Issues:** Should evacuation be attempted in high-rise fires, and, if so, should elevators be used?

**Policy Utility:** High for fire professionals and code-
writers. One of the major issues in high-rise fire safety is whether to permit the use of elevators for evacuation or movement of building occupants.

**Internal Validity:** While the arguments are strongly made, supported by cited cases, and generally sound, the author ignores the length of time for evacuation, the resulting safety hazard, panic potential, and the present unavailability of reliable elevator service.

**External Validity:** The situations and concepts referred to are generally involved in all high-rise fires. Although these views are at present contrary to those of fire departments, a number of persons are beginning to lean in this direction.

**Summary:** The author challenges two currently accepted concepts: (1) that total evacuation should not be considered in high-rise buildings, and (2) that elevators should not be used for occupant evacuation. He, in turn, proposes three basic concepts: (1) smoke movement in tall buildings is unpredictable, as are fire safety provision violations; (2) people want to get out of a burning building; and (3) people will usually try to use their normal exits.

He refers to a case in which complete evacuation was used (One New York Plaza—the building was not completely occupied, however), one in which elevators were used at least partly successfully (New Orleans Hotel), and the use of elevators by fire-fighters, "the people who suggest we reserve one for them, ... who get into just as much trouble with them as the unwitting stranger." He argues, therefore, that effort be put into designing elevators that will function during a fire emergency and suggests federal regulations if necessary.

**Discussion:** Although Skilling is not a fire professional, he makes some of the most telling arguments in favor of fire use of elevators, supported by references to several important sources. However, he ignores some very important factors. First, evacuation time for tall buildings can easily exceed a half hour by stairway and theoretically approaches a half hour by elevator even if it proceeds smoothly; increasing elevator capacity beyond that required by present codes would be very expensive. Second, no elevators are now available that offer the required operational reliability.

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R6-8


**Abstract:** Exit requirements of building codes are discussed and compared with a formula for evacuation times based on empirical values of walking speed. Tables of evacuation times are presented and compared with times from actual drills. The conclusion is that both actual and calculated evacuation times by stairs of tall buildings are too long to depend upon this strategy for achieving occupant safety.

**Audience:** Fire-fighters; useful also to code writers and architects.

**Issue:** Can high-rise buildings be totally evacuated in a reasonable time?

**Policy Utility:** High for fire department administration.

**Internal Validity:** Although the agreement of empirical and theoretical results is poor, the general conclusion is valid.

**External Validity:** The conclusion that evacuation times would be prohibitively long would hold for high-rise buildings in general.

**Summary:** The chimney effect in tall buildings will, in many cases, fill stairway shafts above the fire floor with smoke, requiring occupant safety factors other than evacuation times to be considered. Nevertheless, evacuation times must be considered. The chimney effect in tall buildings will, in many cases, fill stairway shafts above the fire floor with smoke, requiring occupant safety factors other than evacuation times to be considered. Nevertheless, evacuation times must be considered.

Most North American building codes base exit requirements on a National Bureau of Standards and National Fire Protection Association study done in 1935. Findings were that, in railroad stations, shoulder height lane width of 22 in. permitted free movement, and was called "unit exit width" (uew). Flow rate was 45 persons per min (ppm) on stairs and 60 ppm through doors, per uew. In high office buildings, many floors feed into the same stairway; therefore 1-1/2 sq ft per person of standing room should be provided for the occupants of half the floors above the first.

In 1956, the London Transport Board found that all movement stops when passage way space is reduced to 2 sq ft per person. 6-ft-wide stairs could pass 130 ppm, but a central handrail cut this to 105 ppm. Stair flow rates measured at concentrations of 2 to 15 sq ft per person showed that speeds leveled off at 158 ppm above 10 sq ft per person, and max flow rate of 45 ppm per uew occurred at 3 sq ft per person and 75 ft per min. Moving up stairs was less than 3 percent slower than moving down.

A formula is adapted from a 1952 British study, which provided for 2-1/2 min for all building occupants to enter the stairway:

\[
N = \frac{(N + n) / (r \times u)}{N} = \text{number of occupants above 1st floor;}
\]

\[
n = \text{lesser of: number of people per floor, or 1/3 the number of sq ft of stairs per floor;}
\]

\[
r = \text{discharge rate, ppm per uew = 45 if persons per floor is greater than 3 times stair area (otherwise, use values from paper's table);}
\]

\[
u = \text{stair width in uew.}
\]
Agreement of calculated T with evacuation times in practice drills is poor. Drill times varied from 0.92 to 2.4 times the calculated times. Long corridors and low population density seemed to cause the differences.

For 44 in.-wide stairs with 99 sq ft stair area per floor, the 1965 National Building Code permits 120 persons per floor in office buildings and 60 in residential buildings. A table based on the formula for T for this stairway shows the maximum persons per floor to permit evacuation of buildings (from three to 20 stories high) in 10, 7-1/2, and five min. Another table shows evacuation times for 15 to 50 story buildings for densities of 240, 120, and 60 persons per floor for this stairway; all of these times were considered too long, ranging from nine min for a 15 story building with 60 persons per floor, to 131 min for a 50 story building with 240 persons per floor.

Elevators are sometimes considered as an alternative means of evacuation. Normally elevators are designed to evacuate 20 percent of occupants in five min, resulting in a minimum evacuation time of 26 min if elevators don't fail.

Discussion: The basis for the evacuation time formula is not quite completely stated and apparently is modified from references. Calculated times were compared with drill evacuation times, but correlation was poor and possible reasons were stated only casually. No statistical methods were used. Times appear to be very sensitive to factors not included in the formula. No replication to evaluate variation is mentioned.

R6-7

Abstract: Four cases of elevator operation during fires are briefly presented in this paper. Possible reasons for elevators being at fire floors are listed, and codes and recommendations are given for elevators in fire.

Audience: Fire-fighters, code writers, and building equipment designers.

Issue: Elevator reliability during fire emergency.

Policy Utility: Medium for audience cited.

Internal Validity: Highly suspect. No real evidence presented.

External Validity: Not applicable.

Summary: Four fires in which elevators found their way to the fire floor are cited, including the One New York Plaza fire in August 1970. The contention is that, in each case, the elevator was summoned to the fire floor by an actual call, rather than by a spurious, fire-generated call.

It is claimed that there are no elevators in the United States that are normally summoned by heat at the call button, and that such a spurious call could be generated only when heat destroys the call button mechanism. Designing buttons to withstand the intense heat would not eliminate (a) car calls for the fire floor, (b) hall calls from fire floor by passengers who don't wait, and (c) automatic system dispatching to fire floor.

An ANSI Elevator Code Committee recommended that elevators be returned nonstop to the lobby and doors opened in case of fire, in order to avoid the possibility of stopping at the fire floor or of stalling in the hoistway where smoke is likely to move. Elevators could then be operated only by key switch on independent service; doors would close if the door button were released before the door was fully opened.

The Committee is also considering recommendations to have doors close after a set time if affected by smoke, and to eliminate requirements for venting hoistways. Recommendations include warning signs to prevent use of elevators during fire, pressurizing hoistways, and the use of elevator vestibules.

Discussion: This paper, by an employee of Otis Elevator Co., is less than convincing. No indication is given as to how conclusions were reached that elevators in the fires responded only to legitimate calls and not to spurious fire-initiated calls. The question of elevator reliability in fire is thereby hedged. The issue of evacuation and the part to be played by elevators is largely ignored. The possibility of elevator improvement is not even mentioned.

R6-8

Abstract: Recommendations are presented in this paper for revision of the New York City Building Code, based on two tall office building fires in New York during 1970.

Audience: Code writers, architects, engineers, and fire professionals.

Issue: What code revisions can improve fire safety in high-rise buildings.

Policy Utility: High for those involved in code formulation.

Internal Validity: Some recommendations appear to be arbitrary.

External Validity: Conditions considered are typical for high-rise office buildings.

Summary: The Mayor's Advisory Committee on Fire Safety in High-Rise Buildings was formed, and this report written, in response to concern that fires in two tall New York City office buildings in 1970 were the result of "lower levels of fire safety" permitted by recently adopted building code revisions. The Committee's report concludes that the city's new building code did not provide for lower levels of fire safety, that the two buildings
...instigating the study were built under the old codes, and that buildings had not been completed, although partially occupied, leading to several unique fire safety problems. The recommendations are only to office buildings but have applicability to other occupancies.

Fire code amendment is recommended to require a Fire Safety Plan, a Fire Safety Director, and fire drills.

Building code amendments are recommended as follows (the years given indicate the term allotted for compliance of existing office buildings):

Compartmentation: Maximum open area to 7500 sq ft for one-hr partitions, 15,000 sq ft for two-hr partitions (affected also by number and type of smoke and heat detectors), unlimited for fully sprinklered areas. Stories under 40 ft exempted (ten years).

Ventilation: New buildings require smoke shaft with fan to give one change per min. Old buildings require stairwell pressurization.

Signs: Indicating use of stairways (rather than elevators) for building evacuation, unless instructed by firemen, are required.

Stair Doors: May all be locked from stair side in buildings under 100 ft high; if over 100 ft, only every fourth floor need be openable from both sides or equipped with fall-safe opening devices.

Showroom spaces: Sprinklers required for areas over 750 sq ft (one year).

Interior alarm and voice systems: Called Class E, required, including a fire command station in lobby of entrance floor (three years).

Elevators: Control devices required to recall elevators to terminal floor in case of fire alarm. Either three or all (whichever is less) elevators in a building must be equipped for firemen’s service; remaining elevators (in new buildings) to be independent. Interlock wiring must be high temperature resistant for all elevators in new building; fire service elevator in existing building (three years).

Fire detection devices: Manual fan controls are required for central air-conditioning systems. Products of combustion or smoke and heat detection devices are required at return air inlets, elevator landings, and any areas over 10,000 sq ft (three years).

The report mentions the need for emergency power during a fire and for consideration of office contents but does not elaborate on these because a separate committee is considering the former, and a directive on the latter has been issued by the city.

Discussion: The recommendations are the consensus of professionals in fire-fighting, architecture, engineering, insurance, real estate, labor, and government. However, some of the recommendations appear to be arbitrary, and tradeoffs, while mentioned, are handled intuitively.

The problems this set of recommendations addresses have been verified for office buildings and other occupancies too. Some of the recommendations—e.g., use of stairs rather than elevators for evacuation—have been challenged by other experts.

R7-1

Abstract: Fires in manufacturing buildings and in distributive trades buildings in the United Kingdom in 1963-64 are analyzed in this paper. Nine types of construction are defined by considering three types of walls and three types of columns. For each construction type and for four occupancy types in each year, the authors tabulate the proportion of fires that spread beyond the room of origin. A model that treats the effects of the three wall types, three column types, and two years as separate and additive is proposed and then fitted to these proportions. Fire spread in buildings with timber framed walls is greater than with other walls, in all four occupancies. The differences are statistically significant in three of these cases. When construction is taken into account, there is no statistical difference between the two years in all four occupancies.

Audience: Researchers and fire professionals.

Issue: Can the effect of construction on fire spread be quantified?

Policy Utility: Moderate. The method indicates that it may be possible to use actual fire experience to compare types of construction. A lot remains to be done before it can be used to guide building code decisions. But it is a step forward. Compare with review of Harmathy (R7-24).

Internal Validity: Adequate.

External Validity: The finding that 1963 was not significantly different from 1964 for each of the four occupancies is heartening. It indicates, at least in the case of construction and fire spread, that it is reasonable to expect the future to be like the past. As the authors admit, the construction types were chosen because data were available; they would have preferred different definitions. They also indicate that it might be true that building size, use, and contents are associated with construction, and that if so, further investigation is needed.

R7-2

Abstract: Fires in the United Kingdom in 1963 are classified in this paper by the time from receipt of the alarm until the first fire company is on the scene (called
attendance time). The proportion of fires that spread beyond the room of origin are examined for each class to see if spread is more frequent when attendance time is large. This is done for several types of buildings, defined by occupancy and an a priori judgment of risk. No consistent attendance time effect is found.

**Audience:** Everyone.

**Issues:** (1) How much more likely is fire spread when response time goes up? (2) How much more likely is fire spread in buildings thought to be risky than in those deemed not so risky?

**Policy Utility:** Potentially high. This work suggests the answer to question (1) is little if at all. Assuming fire spread is a good indicator of monetary damage (see Melinek, Baldwin, and Thomas (R7-3)), then adding companies would reduce monetary loss very little; disbanding companies would increase it very little.

**Internal Validity:** The observed spread in different risk classifications may reflect differences in both the rate of spread and the number of companies initially responding. Also there are some statistical significance questions.

**External Validity:** Hogg (R7-7; R7-8) finds consistent increases in the proportion of fires that spread as response time goes up.

**Summary:** The influence of “fire cover” and attendance time on the proportion of fires that spread beyond the room of origin is studied for five types of fires: fires in single story residences and in single and multistory manufacturing and distributive trades buildings in the United Kingdom in 1963, excluding all those that did not spread beyond the item first ignited. The fire cover standard for a building specifies the number of fire companies to respond and maximum attendance time for each. It ranges from three engines within five, five, and eight minutes (class A) to one engine within 20 minutes (class D). The risk of fire spread, as estimated by the brigade, determines a building’s fire cover. Within each type, a fire is classified according to the fire cover standard for the building involved and whether the actual attendance times of the brigade were five minutes or less, six or seven minutes, or eight minutes or more. A model relating the proportion spread to the risk and attendance time classes is specified. (The logit of the proportion is the sum of the two effects, no interaction.) The risk and time effects are calculated separately for each of the five fire types. The model fits the data well, as indicated by Chi-square statistics. There is no consistent attendance time effect. There is no consistent risk class effect, although there are some statistically significant differences: in single story manufacturing buildings, a larger proportion of D class fires spread than A or B; in residences, more C spread than B or D.

**Discussion:** If one company is as likely to contain a fire not yet spread from room of origin as three are, then the risk and attendance time effects can be interpreted straightforwardly. If not, then the larger number sent initially to class A risks should mean that fewer of them would spread than the class D risks. In this case, the risk class effect is a mixture of the true risk of spread and of the different initial response to the different types of fires.

The statistical significance of the risk class differences that were found is open to question. It is not clear whether each pairwise difference was evaluated using the usual t-statistic or whether simultaneous inference techniques were used on all pairs of risk classes at once. If the former, then with four risk classes and five fire types, one would expect to find a significant difference or two even if there were no risk class effect.

Plots of fraction spread versus attendance time of the data in Hogg (R7-7) suggest a relationship for single and multistory dwellings and industrial-commercial occupancies. Yet no relationship is found here. Differences between the two studies are: Hogg uses some 1963 and all 1967 fires; she separates fires fought by citizens before the brigade arrived from those not fought; she treats attendance times in one-minute classes; her model is Markov, this one is logit; she does not assess statistical significance. In Hogg (R7-8) it is postulated that citizens tend to fight small fires and leave the larger ones alone. This could explain why she is able to find a relationship.

If D risks are less valuable than A risks, it would not be wise to use the relationship in Melinek, Baldwin, and Thomas (R7-3) to relate monetary loss to spread.

**R7-3**


**Abstract:** Fires in buildings in the United Kingdom in 1963 that spread beyond the item first ignited are considered in this paper for nine different occupancies. For each occupancy, the proportion of fires that spread beyond the room of origin and the proportion large—that is, those needing at least five jets (hose streams) for extinguishment—are tabulated. If residential fires are excluded, the proportion large is roughly proportional to the cube of the proportion spreading. (The proportion spread runs from 21 percent for “financial” occupancies to 41 percent for “other distribution;” the proportion large is less than 1 percent for “financial” and almost 6 percent for “other distribution.”) A theoretical model of fire spread is developed and compared with the cubic relationship.

**Audience:** Researchers and possibly fire professionals.

**Issue:** Can data on fires that spread be used to predict the frequency of large fires?

**Policy Utility:** A potentially valuable link in relating
policy to monetary losses. Being able to predict the incidence of large fires from that of fires that spread beyond the room of origin might be useful. Fires that spread are far more common, so that less time and effort would be needed to see how different policies affect fire spread.

**Validity:** The spread-size relationship was derived by regression. Therefore, one must ask, when policy is used to change the proportion of fires that spread, will the relationship still hold? Also, spread may not be a consistent measure of monetary damage across risk classes (see R7-2).

The theoretical spread model is based on a chain of reasoning with several unverified links and should be considered quite speculative.

**Summary and Discussion:** Fires in buildings in the United Kingdom in 1965 that spread beyond the item first ignited are considered for nine different occupancies: manufacturing, retailing, distribution, financial, hotels, transport, entertainment, government, and residential. (There were 400 to 30,000 fires per occupancy.) For each occupancy, the proportion of fires that spread beyond the room of origin and the proportion large—that is, those needing at least five jets (hose streams) for extinguishment—are tabulated. If residential fires are excluded, the proportion large is roughly proportional to the cube of the proportion spreading. (The proportion spread runs from 21 percent for financial to 41 percent for other distribution; the proportion large is less than 1 percent for financial and almost 6 percent for other distribution.)

For distribution occupancies, the proportion spread and the proportion with losses over £10,000 (approximately $24,000) are tabulated for the six years 1963-1969. The cubic relationship holds well here too.

A theoretical model of fire spread is developed and compared with the cubic relationship. The theoretical model considers a building as an array of rooms; in one version, the chance of spread from one room to a particular neighboring room is a constant, not influenced by whether, when, or where other spread occurs. (A room in the center of a one-story building has four neighbors; a room in the center of a multistory building has six neighbors, four on the same floor, one above, and one below.) Analytic and simulation calculations are made of the average number of rooms burned per fire for one-story and multistory buildings. Interpreting $s$ times the number of neighboring rooms as the proportion of fires that spread beyond room of origin, they find that the cubic relationship would fit pretty well if a large fire were a fire that spread to at least four rooms. This spread to four or more rooms is consistent with the average square footage burned in large fires.

For eight of the nine occupancy classes, the proportion of fires needing five or more jets is approximately equal to 1.2 times the cube of the proportion spreading beyond the room of origin.

A theoretical model fits this observed relationship pretty well if spread to at least four rooms is equivalent to needing at least five jets.

Detecting the effect of different policies—from building codes to siting of fire houses—on the rate at which large-loss fires occur is difficult because these fires are so rare. If the link between proportion spread and proportion large is valid, it would make it easier to see differences between policies. One could look for differences in policies by looking at the proportion spreading under each policy. This task is far easier, because there are many more fires that spread beyond room of origin than there are large-loss fires.

The spread-size relationship is based on regression, not cause and effect analysis. If we reduce the proportion of fires spreading, will the proportion large be reduced as the formula predicts? In what way, if any, will it depend on how the proportion spreading is reduced?

The theoretical spread model appears weak and speculative on several grounds. It involves a chain of reasoning that has unverified links. It lacks "face" validity, because it is not directly based on how a fire grows in time and space. And its agreement with the spread-size relationship is suspect. It appears to be mainly a consequence of an (unverified) independence assumption.

Consider a fire that starts in the center room of a one-story structure. It is given a chance to spread to each of its four neighbors; in a simpler model, that chance is $s$ in each case. If any neighboring room is set afire by this process, it is also given a chance to spread (but not to a room already burnt). There is no direct time course to this process, no discovery delay, no fire-fighting, etc.

The authors' more complicated spread model might appear to have time in it. In fact, the time notion used does not follow the progress of the fire but rather allows $s$ to vary.

Further, the agreement of either model with the spread-size relationship appears to be a consequence of the assumption of independence of spread across one room-to-room boundary from that across another, and little on the notion of unburnt neighboring rooms. To see why, consider an even less realistic model. A fire starts in a room. Just before going out, it has chance $u$ of igniting exactly one of its neighbors. That room, just before it goes out, has chance $u$ of igniting exactly one of its neighbors. And so on. Then the number of rooms burnt has a geometric distribution, and the chance that at least four rooms burn is $u^3$. Note that $u$ is the chance that a fire spreads from the room of origin, so that we have a cubic relationship between proportion spread and proportion large. The chance that the fire goes to another room is independent of the number of rooms already burnt, a critical but unverified assumption. The difference between the authors' models and the one just presented is that the authors' consideration of unburnt neighbors alters the value of $u$. For example, it is $4s$ for the first room burning in the center of a one-story building and 3s for the next room to ignite. But it appears that
the crucial reason for the good fit to the cubic model is that four or more rooms alight means that the fire was not halted within three room boundary crossings, and that chance is roughly proportional to the cube of the chance of an average single crossing.

R7-4

Abstract: In this paper the proportion of fires that spread beyond the room of origin is tabulated and analyzed for various "types" of fires. About a quarter of the fires spread; the fraction spread was highest (42 percent) in multistory storage buildings and lowest (11 percent) in multistory flats. The proportion spreading was higher at night than during the day in all 11 cases; on the average it was twice as large. The proportion spreading was higher in older buildings than in newer ones, in most of the occupancies; on the average, perhaps 50 percent larger in pre-1920 buildings than in those built after 1950 when more stringent building codes went into effect. There was no consistent difference between the risk classes in proportion spreading, and no response time effect was found.

Audience: Researchers, fire chiefs.

Issue: What factors influence fire spread?

Policy Utility: Possibly useful in tailoring manning, initial dispatch, and other deployment policies to place and time.

Internal Validity: Adequate. The influence of risk class on response time implies that the failure to find a response time effect must be taken with a grain of salt.

External Validity: Can it be integrated with the spread-loss relationship of Melinek, Baldwin, and Thomas (R7-3)? Do the findings hold outside the United Kingdom?

Summary and Discussion: Originally the fire brigade attendance time was to be used in defining fire types; but preliminary analysis of the data indicated that the proportion spreading did not appear to increase as attendance time increased, so it was not included.

Each of seven occupancies (industrial, office, residential, etc.) is analyzed separately; if the data were available, both single and multistory buildings were looked at. Discovery is categorized as either "night" or "day"; there are four risk classes; and building age is pre-1920, post-1950, or in between. A model that relates the probability of spread from room or origin to these three effects (discovery, risk, age) is specified. (In it, the logic of the probability is the sum of the three effects, with no interactions.) The model fits the data well as Chi-square statistics indicate.

Earlier work (Melinek, Baldwin, and Thomas (R7-3), for example) indicated that proportion spreading may be a good predictor of large loss fires. Knowing the difference in proportion spreading for different times of day in different occupancies can be a useful link in decisions on how many fire companies to dispatch at different times of day in different areas, or choosing number, location, and manning of stations, etc.

The beginnings of a quantitative measure of the effects of strong building codes could be lurking in their analysis. Simultaneous consideration of the three factors and the use of statistical tests is good practice. Looking for statistically significant differences among them using the usual t-statistics is somewhat worrisome. Simultaneous inference methods are available, and they indicate that larger differences are required before one claims significance, if one wants to attach a probability (significance level) to simultaneous statements about all the differences.

Risk class determines the "fire cover," which specifies the number of fire companies desired and attendance time for each. Consequently, risk class partly determines the actual attendance times, and this may explain the absence of both an attendance time effect and a risk class effect. (See Baldwin and Thomas (R7-2).)

The proportion spreading being about twice as large at night as during the day would imply, using the cubic relationship in Melinek, Baldwin, and Thomas (R7-3), that the chance that a fire at night results in a large (over £10,000) loss would be about eight times the chance that a daytime fire would be large. It would be useful to explore this implication.

R7-5

Abstract: After midnight, both the proportion of fires that spread beyond the item first ignited and the proportion of those that also spread beyond the room of origin are higher at midday. A linear relationship between these two proportions is found by regression. The paper also indicates that both proportions increase as attendance time increases. The time to control the fire also increases with attendance time.

Audience: Researchers and perhaps fire professionals.

Issues: (1) Is there an association between fire spread beyond item first ignited and subsequent spread beyond room of origin? (2) Is it possible to develop, justify, and calibrate (on real data) simple models of the rate of fire spread and extinguishment?

Policy Utility: A valid model of the sort attempted in (2) would be very useful link in relating policy to monetary and life loss. (For relating spread to dollars, see Melinek, Baldwin, and Thomas (R7-3). For relating spread to life loss, see North and Baldwin (R8-8).) It is
not clear what one could do with associations such as those sought in issue (1).

**Internal Validity:** For the spread model, better than Molinek, Baldwin, and Thomas (R7.3) because more representative of the process, but still lots of hard to verify links in the reasoning. For the associations, somewhat shaky.

**External Validity:** The increase in proportion spread as attendance time increases is consistent with Hogg (R7.7). However, it was not seen in Baldwin and Thomas (R7.2).

**Summary:** In the first part of this paper the authors analyze fires in 1967 in the United Kingdom to see if \( p_a \), the chance that a fire spreads beyond the first item ignited, and \( p_i \), the chance that it spreads beyond the room of origin if it spreads beyond the first item, are related. The technique is to look at both \( p_a \) and \( p_i \) for various types of fires, where type is defined by building occupancy, material first ignited, floor of origin, building height, time of day, brigade attendance time, and time taken to control the fire. For example, 91 percent of the fires occurring between 2 and 3 a.m. spread beyond the item first ignited and 36 percent (of that 91 percent) spread beyond the room of origin. That is, for fires at that hour, \( p_a = 0.91 \) and \( p_i = 0.36 \). For fires occurring between 11 a.m. and noon, \( p_a = 0.76 \) and \( p_i = 0.18 \), both lower than the 2-3 a.m. values. So \( p_a \) and \( p_i \) appear to move together. The idea is to see if they do when all 24 hours of the day are considered, when five different building heights are considered, and so on. When \( p_i \) is treated as a linear function of \( p_a \), statistically significant regressions are found between these two probabilities for three different ways of classifying fires. They are time of day, brigade attendance time, and time to control. The proportion spreading beyond room of origin increases with attendance time, where the latter increases in one-minute intervals. A plot of the average control time (time from brigade arrival until the fire is out, apparently) vs. attendance time, for fires not already out when the brigade arrived, is very well fit by the line \( C = 5 \text{ minutes} + 0.56 \times T \). This then gives the germ of an escalation model, half a minute more of fire-fighting for each minute’s increase in response time.

**Discussion:** In Part I of the paper the question is, Why should the relationship, if any, between \( p_a \) and \( p_i \) be linear? Relationships were sought for types defined in 11 different ways and statistically significant ones were found for three. But the more ways you look at things, the more likely you are to find a spurious relationship. It would be nice to see if the three relationships hold for (say) 1968 fires.

Excluding fires that are out on arrival from the relationship between control time and attendance time excludes something important. What happens to the proportion that are out as attendance time increases?

Part II of the paper proposes a physical model of the fire’s growth until brigade arrival and its decline thereafter. \( S(t) \) is the size (in square feet, say) of the area burning at time \( t \). Two growth laws, which apply until the brigade arrives, are considered. They are:

\[
\frac{dS}{dt} = aS \\
\frac{dS}{dt} = bS^n
\]

In the former, the growth rate is proportional to the current size, and the authors suggest that this might apply to small fires. In the latter, growth is proportional to the perimeter (circumference) of the fire, which seems more appropriate for large fires.

By assumption, after the brigade arrives, growth ceases. Extinguishment efforts decrease the size of the fire, and reduction to zero area corresponds to control (extinguishment) of the fire. Again, two extinguishment laws are considered. First, constant area reduction

\[
\frac{dS}{dt} = -q
\]

considered appropriate for small fires; second, increasing area reduction with time

\[
\frac{dS}{dt} = -r(t - \text{time of brigade arrival})
\]

considered appropriate for larger fires (where more units arrive as time goes on). (In this case, one might prefer \( \frac{dS}{dt} = E + vt \), rather than forcing the area extinguished during minute 2 to be half that during minute 4, and so forth.)

Combining each growth model with each extinguishment model yields four possible relationships. They measure time starting from fire discovery and so treat the size at that instant as a constant. In what is apparently an oversight, \( S_0 = 0 \) in the model derived from (2). The results are:

\[
C = \left( \frac{S_0}{q} \right) e^{\alpha T} \\
C = (2S_0/r)^{1/2} e^{rT/2} \\
C = \left( \frac{b}{2q} \right) T^2 \\
C = \left( \frac{b}{r} \right)^{1/2} T
\]

where \( T \) = time from discovery to arrival, \( C \) = time from arrival to control.

with \( S_0 > 0 \), the latter two relationships become

\[
C = \left( \frac{b}{2q} \right) T^2 + S_0/q, \\
C = \left( \frac{b}{4} \right) T^2 + 2S_0/r \right)^{1/2}.
\]

Just looking at the relationships, it is clear that control time is a convex increasing function of attendance time in the first five cases; taking the derivative shows it true in the sixth. The relationship is strictly convex except in the fourth case, where it is linear.

The authors eliminate \( S_0 \) by differentiating, getting \( dC/dT \) in each of the four cases. They estimate parameters by reference to other Borehamwood work, and all the estimates give numerical values of \( dC/dT \) that are in the neighborhood of the \( C = 5 \text{ minutes} + 0.56T \) observed in the 1967 fires.
R7-6

**Abstract:** This paper looks for relationships between fire damage, as measured by whether or not the fire spreads beyond the room (or floor) of origin, and fire duration, which appears to be the time from brigade arrival until the fire is declared extinguished. Only nonresidential building fires in 1963 in the United Kingdom are considered. Considering single-story fires extinguished in less than five minutes, 9 percent spread; of those extinguished in five to nine minutes, 18 percent spread; and so on, up to 70 percent spread in those taking at least 40 minutes to extinguish. A straight line fits the data reasonably well. Within the multistory buildings, 27 percent of the fires in pre-1950 buildings spread; 22 percent of those in the post-1950 buildings spread. Of these decreases, 3 percent occurred because fires in newer buildings took less time to put out; 2 percent because, at any duration, fewer of them spread.

**Audience:** Mainly researchers; fire professionals.

**Issue:** Can how far the fire spread be linked to how long it took to extinguish?

**Policy Utility:** Moderate. Might be useful in linking building code changes and allocation decisions to monetary damage.

**Validity:** Lacks statistical evaluations.

**Summary and Discussion:** Single and multistory buildings are considered separately; of the latter, buildings erected before and after 1950 are considered separately. The author considers 5000 single-story fires first: 22 percent of them spread beyond the room of origin. Considering these figures by duration, he found that of those extinguished in less than five minutes, 9 percent spread; of those extinguished in five to nine minutes, 18 percent spread; and so on, up to 70 percent spread in those taking at least 40 minutes to extinguish. A straight line fits the data reasonably well.

Of the multistory fires, 26 percent spread beyond the room of origin. This is a 4 percent increase over the 22 percent in single-story fires. About 1.5 percent of the increase is because fires last longer; 2.5 percent of it is because, at any duration, more of them spread.

Within the multistory buildings, 27 percent of the fires in pre-1950 buildings spread; 22 percent of those in the post-1950 buildings spread; 3 percent of this decrease is because fires in newer buildings took less time to put out; 2 percent is because, at any duration, fewer of them spread.

This decreased spread in newer buildings was further analyzed by dividing those fires that spread into "confined to floor of origin" and not so confined. In the older buildings, 8 percent were confined to the floor of origin and 19 percent went beyond it; in the newer ones, 11 percent were confined to floor of origin and 11 percent went beyond it. This is taken as an indication that newer regulations do restrict upward spread.

In short, the paper obtains quantitative relationships between damage and duration for fires in single and multistory and nonresidential buildings, and with the latter, older and newer buildings.

Statistical significance of the comparisons between single and multistory fires and between fires in old and new buildings is not assessed. Calculations of the difference between old and new buildings in upward spread use an unjustified assumption of the independence of upward spread and sideways only spread. The statistical significance claimed for the difference is also suspect. In the author's analysis fires in newer buildings are compared with fires in all buildings. It would seem appropriate to compare them with fires in older buildings.

R7-7

**Abstract:** In this paper, the relationship between fire damage and "attendance time" (defined in Hogg (R7-8) as "the time between the call to the fire brigade and the time the first appliance reaches the scene") is sought. Damage is defined in terms of how far the fire has spread. A model is proposed and parameters estimated, using data from over 20,000 fires in the United Kingdom.

**Audience:** Researchers primarily; fire professionals.

**Issue:** Everyone knows that longer attendance times mean more damage. But how much more? In what cases? In this paper specific quantitative relationships for several types of fires are found for damage measured by whether the fires was confined to room or floor of origin.

**Policy Utility:** Very high. A vital building block in the needed relationship between allocation decisions and fire losses.

**Internal Validity:** Are the relationships that are found statistically significant? (The author does not say; the procedure for finding the relationships does not lend itself to statistical analysis.) Is there a relationship between how far an occupancy is from the nearest station and how fast a fire would spread or how long it would take to be discovered? (For example, there are long attendance times to rural fires where, perhaps, lower population density means a higher proportion of fires have spread by the time the fires is discovered. If so, the author's relationship would overestimate the reduction in damage that would occur if attendance times were reduced.)

**External Validity:** Are attendance times reliably recorded? They are given in whole minutes—are they rounded or truncated? Is it always one or the other? Baldwin and Fardell (R7-4) look for but do not find an
Summary and Discussion: Relationships between attendance time and fire damage are developed for eight types of fires. Damage is defined as the stage of the fire when the fire brigade arrives. The stages are confined to room of origin and spread beyond room. When appropriate, the latter stage is broken into spread beyond room of origin, confined to floor of origin and spread beyond room of origin. (Since the stage at arrival could not be observed, the stage at extinguishment was used instead.)

The eight fire types result from considering whether the structure was single story, whether civilians attempted fire-fighting before the fire brigade arrived, and whether it was a private dwelling or an industrial-commercial occupancy. Fires confined to item of origin were not considered. The set of fires studied were all 1967 fires in the United Kingdom and a sample (one-sixth) of those in 1963. This gave over 11,000 multi-story dwelling fires with no fire-fighting attempted before the brigade arrived and over 1000 single-story dwelling fires with some firefighting attempted. The number of fires of the other six types studied were somewhere between. For each type, the fires were subdivided into those where the brigade took one minute to arrive, those where it took two minutes to arrive, and so forth. Most times were between four and seven minutes; for example, over half the multi-story dwelling fires with no previous fire fighting had attendance times of five, six, or seven minutes. About 10 percent of those fires had attendance times of 12 minutes or more.

For each fire type, the fraction of the fires with one-minute attendance time that were confined to room of origin was calculated, as was the fraction with two-minute attendance time that were confined, the fraction with three-minute attendance time, and so on. The same was done with fraction spread beyond room and, where appropriate, fraction spread beyond floor of origin. When plotted, the fraction spread beyond room fluctuates but appears to go up as attendance time goes up. For example, see Fig. 1.

The author proposes a method for fitting a smooth curve to this data. It is derived from a probabilistic model of the spread from one state to the next. (It is a Markovian model.) Its results are also given in Fig. 1.

Similar analysis is done for a ninth fire type, namely those fires where injury, fatality, escape, or rescue occurred. The fraction of those that had a fatality increased as attendance time increased in a manner similar to the increase for the other eight types.

![Fig. 1 — A model of fire spread](image-url)
R7-8

**Abstract:** A way of predicting average monetary loss from attendance time is developed. Depending on the value attached to life, the result is from £10 to £150 per minute for fires in dwellings and about £1000 for industrial-commercial fires. The prediction is based on (a) further development of the fire spread model (see R7-7), (b) association between spread measured in square feet burned and spread measured by whether the fire was confined to the room (or building) of origin, and (c) the relationship between square feet burned and monetary loss. Factor (a) is developed from data on about 150,000 fires, (b) from about 6000 fires, and (c) from about 1000 fires, all in the United Kingdom.

**Audience:** Primarily researchers; everyone.

**Issues:** (1) Can attendance time be used to predict average loss? (2) Can the relationship in (1) be used to specify how many fire companies a city should have?

**Policy Utility:** Very high. The only quantitative association of monetary loss with the time from alarm receipt until a fire company arrives at the scene. If valid, usable to determine the number of fire companies in a city that will minimize the total of fire losses and the cost of providing the fire companies.

**Internal Validity:** As an early venture on a very important problem, a more than reasonable job. Superior to any published U.S. work we have seen. However, the work integrates data of varying quality and reliability into several relationships. There are then many alternative ways to treat the data and many possible places to go wrong. However, even if some details are questionable, the overall results—the value of a minute of attendance time in several situations—is probably in the right ballpark.

**Extenal Validity:** Validity is questionable outside of the United Kingdom.

**Discussion:** One example suggesting that alternative ways of treating the data might be preferable is the following. One parameter of the model that relates fire spread to response time is the fraction of fires that will never spread beyond the room of origin, no matter how long it takes the brigade to respond. Consider the estimation of this fraction that will remain confined for fires in single-story nondwellings, both with and without civilian fire-fighting before the arrival of the brigade. With some fire-fighting, the observed fraction confined to room of origin ranges from .96 at discovery to arrival time of 2 minutes, to .76 at over 20 minutes. The estimated fraction that will forever remain confined is zero. Without fire-fighting, the observed fraction confined to room of origin ranges from .72 at discovery to arrival time of 2 minutes, to .33 at 20 minutes. The estimated fraction that will forever remain confined is .43.

These estimates of the proportion that will never spread appear to run counter to both intuition and the data. One would expect the fires that will never spread to be easy to handle and hence more in the "some civilian fire-fighting" class. Yet the estimates say none is in this class, but some are in the "no civilian fire-fighting" class. Further, in the "some civilian fire-fighting" class, the actual fraction confined starts high, at .96, and drops about .2 as attendance time goes from 2 to 20 minutes. In the "no civilian fire-fighting" class, it starts lower, at .72, and drops more, about .4, as attendance time goes over the same range.

Thus, the validity of these estimated fractions that will never spread is suspect. Although this is disturbing, the overall relationship between losses and response time may still be usable. For example, despite this, the model's predictions of the fraction confined to room of origin as a function of discovery to arrival time agree pretty well with the observed data.

R7-9

**Abstract:** Maximum discovery delays for 14 large fires were estimated by the "Fire Visiting Team." The theory of statistical extreme values is used to construct a distribution of maximum delays and estimate its parameters. These parameters and assumptions about the discovery process allow the average discovery delay to be estimated.

**Audience:** Researchers, fire professionals.

**Issue:** Can discovery delay be estimated reliably?

**Policy Utility:** Knowledge of discovery delay has several uses. Three are: to establish the potential usefulness of detectors; to help judge extinguishment performance (eventual damage is a compound of the delay and of suppression effectiveness, so knowing delay can let us separate them); and to untangle the effect of delay from that of response time on damage.

**Validity:** Very weak. Makes many unjustified assumptions about the discovery process, and some of them are counter to intuition. Uses maximum delays from 14 fires, far too few to draw conclusions.

**Summary and Discussion:** The chance that a fire undiscovered 1 minutes after ignition will be discovered in the next minute is assumed to be independent of t. (That makes time to discovery exponential.) This rate of discovery is called \( \lambda \). But the larger t is, the bigger the fire is; so the chance of discovery ought to increase, not stay constant. This assumption is used to find the type of distribution assumed by the largest (i.e., extreme) delay in a random sample of delays. How this sampling process is related to actual discovery is never made clear.
Somehow the extreme is equated to the estimated maximum possible delay. This estimate was obtained by the "Fire Visiting Team" for 14 large fires; part of the reasoning is, "For example, if it is known that the workers of a factory left...at 6 p.m. and that the fire was discovered...at 10 p.m. the maximum likely delay...would be 4 hours."

The distribution type used by Ramachandran for the extreme would also result from discovery delays being gamma, normal, lognormal, or logistic. The gamma with shape parameter greater than one would have the chance of discovering an undiscovered fire increase with t, so the extreme distribution could be useful. The parameters of the distribution of maximum delays are estimated from the 14 observations by least squares. One of the parameters is known to be λ, the rate of discovery. (This is true only for the exponential.) The average of the maximum delays was 125 minutes.

R7-10

Abstract: Dwelling fires in southern Sweden during the period 1948-1952 were analyzed. Two hypotheses were tested. The first was that for each of four construction types, the distribution of money damage can be deduced from a "fundamental function" that is independent of the amount destroyable by fire. The second was that the fundamental function is independent of the public fire protection provided. The first was accepted; the second rejected.

Audience: Researchers and fire professionals.

Issue: Find a probability density function for damage done by fire in several building classes; estimate their expected losses.

Policy Utility: Moderate. The result that larger losses are expected where little public protection exists suggests its importance.

Internal Validity: In general, the idea is good, the statistical procedure is valid, and the data are sufficient.

External Validity: The analysis was performed only on data from southern Sweden in dwelling occupancies. This raises the question as to whether the results hold outside southern Sweden or even outside the dwelling occupancy class at all. Based on similar studies in New York (see Ignall, Rider, and Urbach, 1975) it would be surprising if the "fundamental" functions were independent of the type of occupancy.

Summary and Discussion: The Data. Let h and b be building construction and protection codes as defined below.

1. Stone or concrete walls and floors
2. Stone or concrete walls and wood floors
3. Wooden houses with plastered walls
4. Other wooden houses

b Type of fire protection
0. Stockholm—professional fire brigades
1. Other big towns—professional fire brigades
2. Towns with nonprofessional fire brigades
3. Rural areas

Let V denote property value (in units of 100 Swedish crowns) and v the maximum amount destroyable by fire.

The data consisted of fires in dwellings in southern Sweden, during the five-year period from 1948 to 1952, extracted from the records of the Central Office of Common Swedish Fire Damage Statistics. Each incident was classified according to its h, b, and V values, discarding those with V < 1 because of reliability considerations.

The model and hypotheses. Hypothesis I: A density for the amount of damage incurred can be deduced from a "fundamental" function independent of the value of v.

Hypothesis II: The fundamental functions are also independent of the value of b.

Let \( s_0(y) \) denote the fundamental function for the group of fires indexed by bh at damage level y. The density for class vbh fires is then given by \( s(x) \) where

\[
s(x) = \begin{cases} 
0, & x < 1 \\
1, & s(x), \quad 1 \leq x < v \\
\int_v^\infty s(t)dt, & x = v \\
0, & x > v.
\end{cases}
\]

And the expected damage, given ignition, is then equal to

\[
\int_1^v t \cdot s(t)dt + v \int_v^\infty s(t)dt.
\]

Previous work done by the author suggested a mortality intensity function \( \tau(x) \) (resembling a measure of the rate at which fires cease to escalate) of the form

\[
\tau(x) = kx^{-\alpha}(1-x)^{-\beta}, \quad a, b > 0,
\]

where x is the accrued proportion of the maximum attainable loss.

If one believes in \( \tau(x) \), then it is not unreasonable to try \( s(x) = kx^{-\alpha} \) as an estimate of the fundamental function (where we understand the dependence on b and h).

Since we must have

\[
\int_1^\infty s(t)dt = 1,
\]
k must equal a − 1. For any realization of losses, $s_1, \ldots, s_n$, with $N = n$ of them equal to $v$, maximizing the likelihood function gives the following estimate for $a$:

$$a^* = 1 + \frac{n}{\sum_i (\ln s_i - (N-n)\ln v)}.$$ 

Some of the wording is difficult to decipher and a guess at what the authors wished to say is: Using the Chi-square method to test Hypothesis I, that there is a common fundamental function within the classes for the appropriate $V$ ranges, reveals that at a 5 percent level the hypothesis is not rejected except when $b = 0$; that is, the model holds for all types of building construction and all communities except rural. Moreover, the same test method reveals that there is no reason to suppose that there is a different fundamental function for building construction types 1, 3, and 4 within a fixed community size for community size types 1 and 3. Building construction type 2 does not seem to fit this pattern.

The same test rejects Hypothesis II. Hence, different community sizes seem to require different "fundamental" functions. Estimates of $a^*$ are typically around 1.5, varying by as much as ± .05 for the various classes.

Validity is adequate except for what seems to be an unnecessary calculation of the expected loss given it is in some loss interval ($s_i, s_i^2, 1$). Now, what should not have been done is to use this conditional expected loss to estimate the expected frequency in the Chi-square statistic; i.e., replacing

$$f\left(\int_{s_i}^{s_i+1} s_v(x)dx / s_v(x), s_i\right),$$

where $x$ is the conditional expected loss. (It is not indicated whether this procedure was used.) It would be surprising if the asymptotic behavior of the Chi-square statistic was insensitive to this kind of manipulation. Also, it would be helpful to know how the estimates of $v$ were made since this is crucial to the analysis.

R7-11

Abstract: A simple model of fire spread is shown to yield a Pareto distribution of loss per fire, the same distribution found in Sweden by Benckert and Sternberg (R7-10). In the model, loss is proportional to the time the fire burns, which is determined probabilistically by a random walk: Return to the origin is extinguishment, a step up corresponds to igniting new material, and a step down corresponds to effective fire-fighting.

Audience: Researchers.

Issue: Can a theoretical spread model be useful?

Policy Utility: A long way from policy, but connecting an empirical loss distribution to a theoretical spread model is a desirable idea.

Internal Validity: Given the narrow assumptions, correctly reasoned.

External Validity: Not as extensive or realistic or connected to actual fire experience as the Melinik, Baldwin, and Thomas work (R7-3) on spread models.

R7-12

Abstract: From the book’s preface:
In this book, various applications of research data in connection with the control of fire in buildings will be discussed. In the main, the control of fire by compartmentation, the use of fire resisting structures, and the use of materials with a low contribution to fire growth, will be considered. The performance of some fire safety elements, such as roof vents and curtains to prevent spread of heat and smoke, will also be discussed. Methods will be given for estimating the expected fire severity in buildings and the requisite protection of structures to resist the fire. Further, a number of subjects related to fire control, such as radiation from one building to another, the hazard of flames from windows and the removal of heat and smoke by roof ventilating, will be considered. Attention will also be paid to economic aspects.

Audience: Everyone.

Issues: What should architects and engineers know about fire? How should they use it in designing buildings?

Policy Utility: Very useful. This book is a reasonable indicator of the policy relevance of much fire research and is far more accessible than the work (papers and research reports) that it draws upon.

Validity: Adequate.

Summary: Chapter 1. A fire first grows slowly, flashes over and burns rapidly, and then decays. These three stages are easy to identify on a temperature versus time graph. The growth stage ends with a rapid increase in temperature, and rapid burning ends when the temperature starts to fall.

In the growth period the temperatures are generally low and their value is therefore unimportant. However, the duration of the growth period is very important, as it determines the time available for escape and the time for effective operation of fire brigades. . . . Large areas of combustible materials . . . are favourable for a rapid growth of the fire. . . . Other factors are: (a) spacing of the combustible materials in the room; (b) size and location of the ignition source; (c) size and location of the openings in the room; (d) wind direction
and velocity; (e) shape and dimension of the room; (f) amount and size of the combustible materials in the room.

So far, existing data about the growth period are inadequate to make reasonable quantitative predictions of the influence of the above mentioned factors.

Chapter 2. Formulas and curves for predicting the temperature course of a fire in an enclosure (i.e., a room) from the quantity of combustible material, the enclosure’s dimensions, and the dimensions of the window opening(s).

Chapter 3. Description of test methods. For example, the author explains how the standard temperature-time curve is used in assessing fire resistance. The curve gives the assumed growth in fire temperature as it burns longer. So the temperature of the test furnace in which a test specimen (say, a door) is placed is varied according to the curve, and how long it takes for the specimen to fail is observed. There is much more on how failure is judged, other aspects of test conditions (pressure, support of the specimen), and so forth.

Chapters 4-8. Deal with the upward spread of fire from windows; spread by radiation to other buildings; roof venting; thermal properties, strength, and deformation of building materials in fire; and theoretical prediction of fire resistance of structural elements (beams, columns).

Chapter 9. This chapter examines the economic aspects of fire. There are data on fire losses in different countries, measured in several ways (percent of GNP, total). Emphasis is on the author’s “minimum total fire cost” method for designing fire resistance. The method is more or less reasonable and a worthwhile first step, but its limitations are enormous. In that it is impossible to calculate or estimate with any degree of confidence.

Discussion: It appears that the complexity of the physical phenomena involved in fire and the difficulty of getting reliable and interpretable results consumes so much effort that researchers have not been able to complete first steps and get on to work that has policy relevance. Consider the book’s emphasis on the structural integrity of a building in which there is a long and serious fire. In such situations, is there not a strong chance that the building will be torn down, whether or not it collapses? If the fire does not spread beyond the floor of origin but smoke destroys the usefulness of all contents above the fire and water destroys everything below it, the relevance of structural integrity is limited.

Abstract: The spread models are similar in spirit to the work of Melinek, Baldwin, and Thomas (R7-3) on spread within a building, although this paper deals with gross spread—i.e., between buildings.

Audience: Civil defense planners, researchers, perhaps fire professionals.

Issue: Can the spread of fire following nuclear blasts be predicted?

Policy Utility: Low (for peacetime).

Internal Validity: Adequate, given the vagueness of the definitions.

External Validity: Weak. This work has less external validity than Melinek, Baldwin, and Thomas (R7-3) since it is farther removed from data that could test any of its assumptions or predictions. (The tone of the paper indicates that the authors were aware of the speculative nature of the work.)

Summary and Discussion: After indicating the scope of the work and distinguishing theoretical from empirical models, the authors develop two fire spread models. Both models use the notion of a “cell”—for example, having the fire remain in the cell or spread to another cell. (What size a cell ought to be—100 ft² or 100 acres—is never discussed. The models never require them to face up to this notion. The reason is that the spread parameters have rate interpretations—how many feet the fire advances in a minute, the inverse of the average fire duration.)

(1) Fire Front Model: The fire starts in the first of a sequence of cells. It either dies out before spreading or it advances to the next cell. If it advances, it either dies out there or advances to the third cell, and so forth. The movement of the fire is couched in language that appears to specify behavior over time, but the result is equivalent to the number of cells burnt before the fire dies out having a geometric distribution.

This model has no visible connection with any phenomena known to be related to fire spread (radiation, temperature, etc.).

(2) Fuel State Models: At time T, each cell is either burnt out, flaming, or not yet ignited. A continuous time Markov process, with stationary transition probabilities and with dimension equal to the number of cells, describes the system.

Other sections deal with other aspects of fire spread. For example, they analyze some data provided by the U.S. Forest Service on the rate of spread of some large urban fires as a function of wind spread and direction, prevailing air temperature, and so forth.

R7-13


R7-14

B. T. Lee, Modeling Individual and Multiple Building Fires, Stanford Research Institute, Menlo Park, California, August 1972. Also NTIS #AD751610.

Abstract: One-sixteenth scale model buildings were
burned, singly and in arrays of nine. The models were one story, constructed of particle board, and had eight rooms, four on each side of a common hall. What was measured? Burning rates (the models were mounted on a scale); thermal radiation outside the models; temperatures inside; when room to room fire spread occurred. They were compared with results for real buildings. Example findings for real buildings at Camp Parks were equal volume doubling time was 2.73 minutes with standard deviation = 22 for Celotex ceilings; it was 7.5 minutes with gypsum board. For scale models doubling times were four to eight minutes, with most of the short times for cardboard ceilings and most of the long times for transite.

**Audience:** Civil defense planners, researchers, fire professionals.

**Issues:** Do you learn anything useful from burning scale models of buildings? From burning real buildings?

**Policy Utility:** Low at this time. Scaling laws—which would relate results from scale models to results in real buildings—are one object of this work. But without a better notion of how policymakers should care how burning rate (for example) scales, the value of this work is measured by its contribution to science, not policy.

**Internal Validity:** Adequate.

**External Validity:** The author judges it by how well the models compare with burns of real buildings. He sees significant discrepancies. But, as indicated above, for policy they may not matter—for example, there is no discernible policy relevance if the burning rate in the models went up when four rooms were ignited instead of one and this did not happen in real buildings.

**R7-15**


**Abstract:** The model predicts the fire state of each of several hundred “tracts” in a city at 15-minute intervals over the 24-hour period beginning with the detonation of a 5-megaton nuclear bomb. It predicts spread within and between tracts. The mechanisms for spread within a tract are radiation and fire brands; for spread between tracts, fire brands. One measure of the situation in the tract is the fraction of its buildings that are currently burning. Statistical characteristics of each tract included distributions of building heights, separations, window openings, etc. The distribution of separations is a function of the current fraction of tract’s buildings that are unburnt. These two fractions are followed through time—they measure the current fire state and predict both radiation spread, considering sources (burning buildings) and targets (unburnt ones), and spread by fire brands, determined by the quantity and angle of fire brand deposit and the number of unburnt buildings where the fire brands fall.

**Audience:** Civil defense planners, fire chiefs.

**Issue:** How much of a city burns and how fast, after a nuclear bomb explosion?

**Policy Utility:** Not much for peace time municipal fire officials.

**Validity:** There are too many interlinked assumptions, and there are independence problems (see Chap. 7 of Part I) similar to those seen in the Borehamwood work in the radiation probability calculations.

**R7-16**


**Abstract:** A computer model for describing a building and the effect of a fire upon it. Special subprograms generate the model of the building and the progress of the fire. Air-smoke flow is not included.

**Audience:** Researchers, research funders.

**Issues:** Whether fire behavior can usefully be predicted.

**Policy Utility:** Low for city managers. High for research funders.

**Internal Validity:** Difficult to evaluate.

**External Validity:** At present low, but will probably improve with further research.

**Summary:** The complex interactions between a building and a fire are studied on a computer. The primary purpose is to identify the information needed for a simulation model to suggest future research areas.

The analysis requires (1) gathering data regarding the building, (2) editing and storing these data, (3) description of fire state over time, and (4) analysis of interaction between fire and the building.

To describe the building, cubicles (modules) apparently by 20 square feet by one story are suggested, the contents (fuel loading), and a set of influence coefficients (conformation of walls, floor, and ceiling); to keep storage requirements within reason, only the influence coefficients between a cubicle and its six nearest neighbors are filed.

To simplify the input of data, much of it is generated. For example, a subprogram designs a sprinkler system for the building, and the resulting design is modified to agree with the actual data. Cubicle coefficients are generated for entire blocks of cubicles (“pseudorooms”) with provision for amending the cubicle description. The coefficients to be stored for each cubicle (related to a standard cib) are (1) BTU content, (2) surface area, (3) gas permeability, (4) aspect ratio (undefined), and (5) inherent burning characteristics. In the present model only BTU content is known; the rest are assumed.

The flow characteristics of the sprinkler system as
successive sprinklers are opened are calculated by another subprogram, based upon detailed description of the piping in terms of equivalent length, inside surface conditions, cubic to which one end is connected, and activation temperature.

To describe the fire and its progress, an approach by Phung and Willoughby (R7-13) is used, which defined nine basic states and 24 state transitions. Current research seeks to express the physics of the fire by defining the conditions for occurrence of the transitions.

The important problem of air movement has not been solved. While ducts can be treated as cubicles, this has not been worked out. Furthermore, open doors and windows are more important than permeability data, but they can be simulated.

The main program FIRE sets a fire (at random or at specified location), calls data and subprograms, and reports damage after the fire simulation. Data subprograms generate plant description (PLANT), accept building description (ENCODE), generate cubicle data (CUBES), and install sprinkler systems (PIFES). Fire dynamic programs follow the fire development (BURN), determine water flows (FLOWS), determine gas movement (SMOKE), and summarize and compare fire impact (LEARN); utility programs are used for random number generation, inversion of water flow equations, external water usage patterns, and output.

The applications possible range from optimum design of building subsystems, such as sprinkler systems, to on-site prediction of the course of an actual fire, if data for the building have been entered into a data file.

Discussion: The data file created appears to be adequate to model certain aspects of the fire. The six-neighbo: restriction restricts progress to adjacent cubicles for each iteration, but this is probably satisfactory except for radiation. The fire dynamics depend upon the validity of the Phung-Willoughby state model. No data are given for actual computer runs, or are there comparisons with actual fires.

Until the ability to handle air flows is developed, the program would be of little value for tall buildings. Since computer programs are available for calculating air flows in tall buildings, these could perhaps be combined for useful results.

R7-17
E. E. Zukoski, F. E. Marble, and W. D. Rannie, Large Building Fires—Experiment and Analysis, California Institute of Technology, Pasadena, California, January 1970.

Abstract: A proposal for the development of network models of fire spread. The notion is that described in Rockett (R7-16). The elements of the network would be "rooms, hallways, ceiling spaces, etc." The bulk of the paper is a review of fire research that judges the relevance of previous work to what is needed for their network model and suggests new research to fill the gaps.

Audience: Researchers, research funders.

Issue: Is a network model of fire spread feasible and useful?

Policy Utility: Moderate. A step in the right direction. More focus on what you want to know for policy than other work, but still not enough.

Validity: Adequate.

Summary and Discussion: The strength of this work is the critique of existing research from a focused point of view. For example, this enables the authors to make the following point in their discussion of experiments on pyrolysis and flaming induced by thermal radiation:

Finally, these experiments are also unsatisfactory in that they deal with step function application of thermal radiation alone. In general, ignition in a room fire will occur after a sample of material is exposed to a gradually increasing radiant and convective heat transfer, and at present no model exists which allows results obtained for a step function flux distribution in time to be correlated with data for a more realistic distribution.

Proposals for new work based on observations like this seem sound.

The proposal for a network model is not as well-developed. The authors are aware that such an approach needs to be kept simple: "In a very substantial manner, the utility of the network concept rests upon the possibility of describing the essential burning process in a room with innocent simplicity." But their treatment of what they would "look like" is too brief to be considered definitive. For example, their one-dimensional model in Fig. 1 looks as if it should be rotated 90°, but it is not well enough labeled to be sure.

R7-18

Abstract: A fire electronic mass fire simulator is described in this paper. It is an analog device that records temperature histories for each building simulated. Model building-to-building fire spread. Input-output modules are placed on a table in the same geometric configuration as the buildings in the fire situation being studied. Each module has devices for emitting and sensing heat by both convection and radiation and a lamp to indicate whether the building it is simulating is on fire. The control unit was programmed to determine the heat emitted from each building from its temperature history and the heat now incident on it. Results of two runs of the model (at two different spacings) are compared with the Bellflower Street fire in Boston in 1964. The simulat-
ed order of ignition of the structures (17 burned) and the order recalled by eye-witnesses are given. They all agree fairly well. Actual data for two other large fires are given, but not the corresponding simulator data.

**Audience:** Researchers.

**Issue:** Of what use is the electronic simulator?

**Policy Utility:** Low to moderate.

**Internal Validity:** Adequate.

**External Validity:** Not strong. Matching, more or less, the ignition order of one large fire is a pretty weak test of validity.

**R7-19**


**Abstract:** Two buildings were burned, with time to flashover recorded for each room in each building. In each building, the number of rooms flashed over doubles roughly every ten minutes.

**Audience:** Primarily researchers.

**Issues:** Can fire growth be reliably predicted? Is the fire size definition—volume of the rooms in which the fire has flashed over—reasonable?

**Policy Utility:** Moderate. Provides real data that suggest fire growth is exponential, with doubling time on the order of ten minutes.

**Internal Validity:** Looks reasonable, some questionable procedures.

**External Validity:** Consistent with other work.

**Summary and Discussion:** *Ellis Parkway*. The fire was ignited in a second floor room. All window glass in the building was removed to simulate nuclear blast effect. The time of flashover was recorded for each room (there were about 46) in the three-story structure. Flashover was defined from inspection of moving picture, temperature, and gas concentration records. It usually coincided with rapid temperature rise to about 1000°F at points halfway up the wall. For each floor, the author then plotted against t the volume of all rooms that had flashed over by time t. These plots rise sharply, and the second and third floor plots look alike. The author graphed log (V/V0) against t for the first floor and for the second and third together. These plots look linear or perhaps quadratic. The author puts more than one straight line through each of them, for reasons that are not explained. From the straight lines, doubling time for the upper two floors is about 12 minutes for t up to 30 minutes, and three minutes thereafter. For the first floor, where first flashover came 50 minutes after first flashover in the building, and doubling time is slightly longer, staying at 14 minutes for about the first 45 minutes.

**Gary.** A one-story building, again with window glass removed, was burnt. The log (V/V0) vs. t plot looks linear all the way, with doubling time of just under eight minutes. The faster spread, relative to Ellis Parkway, is attributed to the higher winds (20 to 25 mph) in Gary on the day of the fire.

**R7-20**


**Abstract:** Models of various scales and a full-size structure were burned. Times for ignition-to-flashover and flashover-to-barrier-penetrations were measured, and the effect of wind was observed.

**Audience:** Researchers, fire professionals.

**Issues:** Whether model fires can give useful information regarding real fires.

**Policy Utility:** Low for city managers. Low for researchers.

**Internal Validity:** Questionable since comparative data were meager and not well presented.

**External Validity:** Perhaps applicable to small structures.

**Summary:** Test tires were set in half-scale models and in full-scale residence buildings. After invalid results in smaller scale models due to laminar flames, only half-scale models were burned; these were of 12 ft × 12 ft × 8 ft rooms with furniture and had some modifications from actual construction. Full-scale tests were conducted in a three-story masonry and wood-joint structure and a one-story structure with concrete block exterior walls; both had attics and basements.

Test results consisted of data for:

1. Ignition-to-flashover time, an average of 14.24 min for models, was considered representative of the 17-min coverage for full-size fires, all for gypsum walls. The greater insulating value of fiberboard and glass fiber decreased heat loss, resulting in flashover times of about one-half the above.

2. Flashover-to-barrier-penetration time deviations from rated resistance are shown to be within five min for ratings to 45 min. The single point plotted for full-size tests is within the model pattern, but there are too little data to be convincing. Downward spread in models was found to be too fast because of lack of subflooring; in real structures, collapse of room contents often protects floors before joists burn.

3. Wind effects on burning rate were substantial (especially when window area was distributed on two walls to allow better mixing) up to a point at which it was stated that fuel surface area effects began to dominate ventilation effects.

4. Flame pattern results were briefly and unintelligibly stated.

**Discussion:** No statistical analysis of data is presented.
Although the purpose was to validate model tests, not enough analysis and comparative data were presented to be convincing. Effects of deviation of model structure from full-size structure were only casually stated. Limitation of structural types and building configuration would restrict the results, if valid at all, to small residential buildings.

R7-21
E. J. Vodvarka, Urban Burns—Full-Scale Field Studies, Illinois Institute of Technology Research Institute, Chicago, Illinois, January 1970; also NTIS # AD707 454.

Abstract: This paper gives results from burnings of eight real structures. Five of the fires were started inside 2 or 2 1/2 story houses. Example results were:

<table>
<thead>
<tr>
<th>Fire</th>
<th>Time to First Flashover (minutes)</th>
<th>Doubling Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>69-1</td>
<td>7</td>
<td>5 1/4</td>
</tr>
<tr>
<td>69-4</td>
<td>24</td>
<td>4 1/4</td>
</tr>
<tr>
<td>69-5</td>
<td>18</td>
<td>7 1/4</td>
</tr>
<tr>
<td>69-7</td>
<td>3 1/4</td>
<td>1</td>
</tr>
<tr>
<td>69-8</td>
<td>11</td>
<td>9 1/4</td>
</tr>
</tbody>
</table>

Five fires in multistory houses had median doubling time of five minutes, and ranged from one to ten minutes.

Audience: Fire researchers and professionals.

Issue: Do we get consistent and useful results from burning real buildings?

Policy Utility: Moderate.

Validity: Agrees pretty well with Labes (R7-19).

R7-22

Abstract: Several examples are given of the inability of test performance to predict the performance of materials, assemblies, and finishes in actual fires.

Audience: Fire professionals, city administrators.

Issue: What does fire performance in the usual building code tests have to do with performance in real buildings?

Policy Utility: Moderate. Anyone can see there is a problem after reading this.

Validity: Adequate.

Summary and Discussion: Building codes require three types of information: (1) whether a material is “noncombustible”, (2) the fire endurance rating of a material or assembly, (3) whether a finish is flammable. The author points out some of the inadequacies of the definition of noncombustible in the National Fire Protection Association, Fire Protection Handbook (13th edition), Boston, 1969. For example, the definition calls a material combustible if it fits in any of three categories. The first is “materials no part of which will ignite and burn when subjected to fire.” The author notes that temperature and duration of the fire are not given so that it is “almost meaningless as a definition.” Other inadequacies include difficulties of deciding whether a material with a surface coat is combustible and the absence of standards for smoke and toxic gas production in the definition.

The story is much the same for fire endurance ratings: “It has been the author's experience that many representatives of producers, designers, and inspection authorities misinterpret and misapply test results.” One problem is relating test results to building design. For example, in most tests the specimen is restrained. Apparently, when restrained, concrete retains much of its strength; but in curtain wall construction, it would not be restrained.

With respect to flammability of surface finishes, the author indicates that flame spread ratings by the tunnel test were designed to allow comparison of different materials under similar conditions, not to represent actual fire conditions. Therefore, “finishes should be tested for flame spread in the manner intended for use and over the substrate to which they are to be applied.” He indicates the need for the latter by noting that you cannot add the flame-spread ratings of the surface and the substrate (say veneer and wallboard). He also indicates that the adhesive may play a dominant role.

R7-23

Abstract: The paper discusses laboratory tests of fire endurance and resistance of materials and assemblies and attempts to relate them to fire behavior in real buildings and how those buildings should be designed.

Audience: Code enforcers and writers, researchers, fire professionals.

Issues: Do test results predict behavior of real fires? Can test results be used in building design?

Policy Utility: Potentially high, but actually low because of inadequate internal validity.

Internal Validity: Very weak. The paper just does not hang together. Consider the paper’s second sentence, “On the one hand, there is a strong tendency to attach an absoluteness to test results that will broach no exercise of judgment.” None of the dictionary meanings of “broach” fits here. The closest—to open up for discussion—suggests that the author means “allow.” But there is
R7-24

Abstract: This paper presents the ideas of Harmathy (1972) for architects. Indicates that fire duration and the temperature-time course of the fire depend on both the fire load and the window area, so that design choice with respect to windows determines what fire endurance rating is necessary in the structural components. But building codes are not written this way.

Audience: Architects.
Policy Utility: Moderate.
Internal Validity: Adequate.
External Validity: Suspect. None of the work on design for fire safety that we have seen attempts to look at a sample of past fires to see if the predictive machinery of their graphs and equations actually worked out in practice. There are test furnace results on failure of structural members and the measurement of temperature and fire duration in burning model rooms, but no empirical integration of the two processes. If architects and code writers are to be persuaded, some after-the-fact analysis of real fires would help greatly.

R7-25

Abstract: A method is given in this paper for estimating, for a given structure, the expected life and property loss due to fire. The method takes into account the building's size, construction, occupancy, and service life, whether it has sprinklers or detectors, and other features. Expected loss is compounded from the chance of fire occurrence, the chance of its spread, and the value at risk.

Audience: Fire professionals; architects.
Issue: Can expected lifetime fire loss be predicted from building characteristics?
Policy Utility: This paper is a first step, outlining a useful approach. But real application would require verifying its assumptions and estimates, which is a large task.
Internal Validity: The paper strings together many estimates and assumptions, each of which is more or less reasonable. It is not clear whether, in sum, their errors cancel or multiply. While superior to Shpiberg and DeNeuville (R4-28), it is still suspect. It has the "many seams" problem of Hogg (R7-7).

External Validity: The data behind the estimates are concealed, so it is impossible to assess their reliability. For example, on p. 4, "An estimate, using statistical data from various sources, shows that a reduction of the probability of significant fire occurrence by a factor of 3, due to sprinklers is a reasonable assumption." But the supporting data are neither furnished nor referenced, and a "significant fire occurrence" is nowhere precisely defined.

R8-1

Abstract: Halpin et al. studied 129 fire fatalities in Maryland, about 40 percent of those occurring over a 28-month period. Primary cause of death, cause of the fire, alcohol involvement, whether the victim tried to escape, and other facts were ascertained, when possible. The prevalence of smoking, often by people who had been drinking, is confirmed as a cause of fatal fires. "Seventy to 80 percent of the victims did seem to be alerted to the fire and did attempt an escape." Carbon monoxide was the primary cause of death in half the cases and was thought to be responsible for 65 percent of the failures to escape.

Audience: Everyone.
Issue: What causes fatalities? How can they be prevented?
Policy Utility: A necessary first step.
Validity: Reasonable as far as it goes. Not enough detail to judge the reliability of the determinants (of cause of fire, cause of death, why escape failed, etc.).

R8-2

Abstract: Data on fire fatalities from the Maryland State Fire Marshall's records for 1967-1968 were collected and examined. The file contained records on 321 fatalities, apparently the total number of known fire-caused deaths during the period. The study emphasized fatalities involving children or smoking. Matches were the prime ignition source of fires killing children. Smoking-caused deaths involved mainly people over 50 years of age and was associated with few deaths of people younger than 30. Fatal fires occurred at a higher rate between 9 p.m. and 2 a.m. than during the rest of the day, when they were uniformly distributed.
Audience: Researchers and fire professionals.

Issue: Identifying causal factors in fire-caused deaths.

Policy Utility: Limited. No variables that are controllable by policy are examined; the report examines only deaths that did occur (rather than taking a sample of the general population and studying the rates of death by type of person, cause, etc.). As noted by the author, the data come from diverse sources (including newspaper clippings) that leave gaps and thus sample bias.

Internal Validity: There are no internal logical contradictions or misused methods. The absence of computing rates is a weakness that could have been easily surmounted since the deaths were a statewide total.

External Validity: The results agree with fire lore. The number of deaths is large enough to expect fairly reliable estimates of population parameters.

R8-3


Abstract: The author would like to know: How do fatal fires start? What are the escape problems? What roles do construction and materials play in fatal fires? Halpin evaluates present sources of fatality data and concludes, "in general, fire fatality data in the United States is incomplete, inconsistent, and inadequate for purposes of statistical analyses."

Audience: Everyone.

Issues: What information about fire fatalities is useful, and how can it be obtained?

Policy Utility: A must for anyone interested in fire fatalities: a good review of the state of the art in fire fatality information and why it is needed.

Internal Validity: Adequate.

External Validity: Adequate.

Summary: Order of Magnitude of Fatal Fires. The accepted "official" figures are computed by the NFPA (National Fire Protection Association). They seem to add 50 percent to the HEW mortality statistics from fires to arrive at the total. The extra 50 percent is an estimate of fire fatalities from transportation-related fires (not included in HEW statistics) derived from a single study performed in 1951. That study is inconsistent with other studies performed in Maryland and California. The NFPA figures are often quoted.

Analysis of Age of Victims. HEW figures are adequate, with age-specific fatality rates calculated.

Causes of Death. Classifying causes as either basically asphyxiation or burns, figures vary from about 70-30 burns to asphyxiation, to 70-30 asphyxiation to burns. Given the present medical methodology and lack of autopsies in most cases, Halpin feels that any figures on cause of death are conjecture.

Ignition Sources. The present sources of data rarely distinguish clearly between cause of fire and source of ignition. For example, in a "careless smoking" fire the smoker causes the fire and the cigarette is the source of ignition. This distinction is not made often enough. One of the few consistencies in the data is that about a quarter of all fatal fires are caused by smoking carelessness.

Main Sources of Data

(1) HEW-Mortality Statistics Section. All states in the HEW reporting system must provide a death certificate for 90 percent of all deaths. How many fire deaths are knowingly excluded, for lack of a death certificate? Also, the definition of a fire fatality varies from state to state.

(2) NFPA. Besides estimating total fatalities, the NFPA analyzes multifatality fires, relying on voluntary cooperation from the local fire service. Other special NFPA studies also involve cooperation from whatever data sources they can find.

(3) National Safety Council. Not up to the standard of the HEW data.

(4) Insurance Information Institute. Collects no fatality information from insurance companies. Instead, they use the NFPA and National Safety Council data.

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R8-4


Abstract: This study uses answers to a questionnaire administered at the scene of nearly 1000 fires to more than 2000 people.

Particular attention was paid to whether a person moved through smoke and whether he left the building. Some findings: When there was smoke, over half the people moved through it, often more than 10 yards and occasionally farther than they could see. People were often ignorant of existing escape routes; they often thought there were recognized escape routes when such routes did not exist. "Training appears to have remarkably little effect on first action taken."

Audience: Architects, everyone.

Issues: How do people behave in fires? How can knowledge of their behavior be used to save lives?

Policy Utility: Moderate. A useful exploratory study, capable of provoking discussion of the myths and real issues about emergency exits and about training, for example.

Internal Validity: A sensible approach, with difficulties acknowledged.

External Validity: Validity questionable outside of the United Kingdom.

Abstract: The authors set out to collect information regarding occupant behavior in (high-rise) fires, with the goal of improving fire safety systems. The questions they intended to address specifically were: (1) How do occupants typically learn of the fire? (2) How do they usually react? (3) How do they usually escape? (4) What positive or negative part do existing systems and procedures play?

The "scientific data base" required for this undertaking proved to be nonexistent. The authors therefore entrenched and wrote a background piece to "define the problem," "to better understand the many problems associated with the response of people to fire emergencies." They nonetheless conclude that fire safety systems can be improved now by taking a "systems-oriented approach" with increased emphasis on the human component.

Audience: Fire researchers, fire safety system designers and implementers (e.g., architects, alarm system vendors, building managers).

Issues: (1) What is known about occupant behavior in (high-rise) building fires? (2) How can this knowledge of occupant behavior be used to improve fire safety systems?

Policy Utility: The usefulness of the paper is in the questions it raises. It calls attention to what should be (but may not be) obvious—namely, that fire safety systems and procedures should take the human element into account.

Internal Validity: The sources the authors rely on in their topical surveys are of mixed, though generally respectable, quality.

Summary: This background piece is basically a survey of topics directly or indirectly related to occupant behavior and fire safety systems. For each topic, the authors lean very heavily on a limited number of sources, which they quote and paraphrase at length. They thus laboriously demonstrate that existing data in related fields is also wanting.

The following is a brief topical outline of the paper:

1. Building codes (trial-and-error incremental code development is contrasted with "a performance-requirement approach using a systems orientation and based on user needs and wants").

2. Existing fire literature (news accounts are of limited usefulness; most fire research neglects the behavior of occupants; three minor studies focusing on human behavior were found and are treated in detail).

3. Related social science findings (behavior under stress, in disasters).

4. The 1972 national conference on fire safety in high-rise buildings (safe zones, compartmental design to isolate fires, etc.).

5. The individual (his physiology, perception, psychology).

6. Extended discussion and conclusions (generally confusing and not worth summarizing).

Scattered among the citations, typologies, and definitions are several fairly good specific questions and examples:

Will building occupants willingly wait in a safe zone if they think that there is a way they can get out altogether?

What things have to happen for a fire alarm to be regarded as real rather than as a test?

What sorts of alarms and exit markings are most likely to attract attention?

Does a given fire safety system avoid problems of "role conflict" for occupants? ("Role conflict" or "role strain" would arise at the time of a fire if an apartment dweller were, for example, both a volunteer fire warden responsible for supervising evacuation from his floor and the parent of a young child playing on a neighboring floor.)

Does the "social structure" of a high-rise community make any difference in occupants' reactions to a fire emergency? Does it matter if the occupants are office workers or partment residents, well-acquainted with each other or anonymous, lower class or middle class? Are there different reactions, and therefore different system requirements, for a fire in a luxury high-rise and a fire in a public housing project?

The quality of discussion is very uneven. Organization is confusing, with many lengthy digressions. The authors are fond of typologies and definitions, offering far more of both than is necessary (e.g., four different definitions of "stress"). The authors are also fond of jargon and tend to adopt the styles of the various disciplines (e.g., in a discussion of "threat" and reactions to it: "When escape is perceived as being possible, the behavior tends to become adaptive for the conservation of the organism").

Despite the emphasis on defining "stress" and reproducing a categorization of stress research, they reject the validity of both laboratory experiments (setting too artificial, subjects too sophisticated) and field investigations ("How is it possible [for the researcher] to maintain objectivity and not be subject to the same stress encountered by [the subjects]?""). They nonetheless recommend planned field disaster research two pages later.

There are other inconsistencies, particularly regarding (1) the goals of the paper itself, which the authors seem to revise as they proceed, and (2) the conclusions that (a) further research is needed because of the "dearth of relevant data...." and (b)
"it is not necessary to wait for the results of long-range research . . . if one considers the already available information in this report."

R8-6

Abstract: All fire deaths occurring in New York City in 1966-1967 that were autopsied (311 out of 534 total fire deaths) were examined for cause of death, elapsed time between fire and death, and characteristics of any burns present. Nearly 60 percent of those deaths occurred within 12 hours of the fires causing them. Respiratory involvement was found in 70 percent of deaths within 12 hours and 46 percent of deaths beyond 12 hours. Smoke poisoning or asphyxia was the most common (a little over 50 percent) primary cause of death in the within-12-hours group.

Audience: Fire department ambulance and emergency room personnel.

Issues: What is the primary cause of death by fire: burns, CO poisoning, smoke poisoning and asphyxia, short range respiratory involvement (pulmonary edema and congestion), or long range respiratory involvement (pneumonia-pneumonitis)?

Policy Utility: Potentially high. An important fire consequence is identified (death by causes other than burns). Such deaths may be reduced by policy-controllable actions (addition of respiratory support equipment to fire engines' gear).

Internal Validity: Adequate. There are no internal contradictions. The arbitrary division of victims into groups based on death before or after 12 hours elapsed since the fire is not justified, but this does not affect validity.

External Validity: Not enough information is presented to judge. There are two questions: (1) were the causes of death correctly identified, and (2) are there systematic differences between the 223 un-autopsied deaths and the 311 on which this study is based? Probably, the information on cause of death is fairly accurate since well-established procedures were used. The second question is important.

Summary: Zikria collected and cross-tabulated data for the 311 deaths caused by fire in 1966-1967 for which autopsies had been performed. The items were:

- Death within or after 12 hours elapsed since fire occurred;
- Pulmonary edema or congestion present;
- Pneumonia or pneumonitis present;
- Burns present (if present, their extent and location);
- CO concentration of victim's blood;
- Indication of smoke poisoning or asphyxia.

The tabulations show that most fire deaths, particularly those occurring within 12 hours of a fire, are due to events affecting the respiratory system rather than to burns. Comparisons between the observed deaths and predicted survival probability show that 76 percent of those with less than 40 percent body surface area burns (who have a predicted survival chance of 77 percent) have some kind of respiratory involvement. Other correlations are noted.

Discussion: The study does not explain or justify the selection of 12 hours time elapsed since fire as a basis for dividing the sample of victims. For many purposes, a better division would use three groups: (1) those dead when fire fighters arrived at the scene of a fire and thus beyond the aid of any new rescue or support scheme but who might have been rescued if the fire department arrived sooner, (2) those dying after fire fighters arrive but before arrival of emergency service support, the prime candidates for life-saving schemes by emergency service personnel, and (3) those dying after leaving the care of emergency service systems, thus falling under the care—and research area—of conventional medical practice of a routine (i.e., other than emergency service) nature. If many of those dying within 12 hours after the fire were dead on the fire department's arrival at the fire, then the key policy variables are fire department response time and reporting time-lapse after fire's onset. If many of those dying are dying from respiratory problems (as this study indicates) during the middle time period (when under the care of an emergency service system; information that is not available from this study) then successful new strategies will be attacking a significant problem. If the deaths occur mostly after victims leave emergency support services, then they fall into the purview of medical research, which is beyond the scope of this literature review.

No statistical testing was done to judge the significance of the correlations or to test for real differences between the before-12-hour and after-12-hour population samples. The differences (if any) between the victims autopsied and those not autopsied were not investigated. This last is the most important weakness of the study since it seems very unlikely that the decision to autopsy is made randomly. If, for example, bodies that are burned very severely are not autopsied (except for identification) because there is nothing but charred victim to examine, then burns loom as a much more significant cause of death relative to CO poisoning and asphyxia. Therefore, the external validity of the study is suspect. However, the study points the way toward investigations that may lead directly to a new and effective life-saving policy.

Zikria's conclusion that resuscitative therapy at a fire and in ambulances and emergency rooms is called for is not justified. There is no information showing death rates with and without such support activity. But it's an important question with two parts: (1) do many victims
die during the emergency service support period, and (2) does resuscitative support improve their chances for survival?

R8-7

Abstract: The authors attempted to get information on every burn case that resulted in hospital treatment or death that occurred in Allegheny County, Pennsylvania over a period of 10-1/2 months. Three research questions were posed: (1) How does the burned population compare demographically with the entire county population? (2) How does clothing involvement affect the burn outcome in general? (3) How does clothing affect outcome when age, sex, and other factors are controlled? The information the authors tried to obtain for each burn case included: date, time, and location of the injury; cause and extent of burn; age, sex, and race of victim; length of hospital stay, if any. For clothing fires, they also attempted to recover the garment involved. Hospital personnel were asked to call a special number when a burn victim arrived; one or more investigators were dispatched immediately, and they did the data collection. Extensive briefings and follow-up were used to assure that the hospital people did call. It is clear that extraordinary effort and care were taken to assure that every burn case was found and all information obtained.

Audience: Everyone.

Issue: What is the nature and extent of the burn problem, with emphasis on the role of clothing.

Policy Utility: Low, unfortunately. There is no apparent focus in the study. There are no answers to the questions—just masses of tables, figures, and supporting narrative.

Internal Validity: The data probably as complete and reliable as anyone will obtain. Perhaps they will be useful for other work—there were 4200 cases. But over 90 percent were out-patient and there were only 36 deaths. So there may not be enough data on serious burns to look at several factors at once.

R8-8

Abstract: In the United Kingdom in 1967 13,000 fires in multistory houses were categorized by hour of occurrence, whether a fatality or other casualty occurred, and whether the fire spread beyond the room of origin. Fires starting in a person's clothing were excluded, because reducing spread is unlikely to change the casualty rate in these fires. (They accounted for 30 percent of all fatalities and 10 percent of all injuries.) Fires confined to the item first ignited were also excluded. Casualties were more common at night than during the day, whether or not the fire spread. At either time, they were more common in fires that spread.

Audience: Everyone.

Issues: How much are fire deaths and injuries associated with fires that spread? If there is now an association, will reducing spread reduce casualties or will it simply weaken the association?

Policy Utility: Potentially high. If the association between spread and casualties turns out to be causal, then fire spread can be used as an intermediate in judging the effect of policy decisions on casualties.

Internal Validity: Adequate. Formal tests of significance do not appear called for—the associations are evident.

External Validity: The findings are consistent with fire lore.

Summary and Discussion: The percentages of fires that result in casualties and fatalities are given below.

| Percentage of Fires that Resulted in One or More Nonfatal Casualties |
|-------------------------|--------|--------|
| Spread                  | Day    | Night  |
| Spread beyond room of origin | 8.0    | 14.6   |
| Confined                | 5.6    | 6.5    |

| Percentage of Fires that Resulted in One or More Fatalities |
|-------------------------|--------|--------|
| Spread                  | Day    | Night  |
| Spread beyond room of origin | 1.8    | 7.6    |
| Confined                | .5     | 2.1    |

Note that a fire at night that spread was 15 times as likely to have a fatality as a daytime fire that did not spread. Note also that 91 of the 151 fatal fires did not spread, and only 60 did. (Clothing fires add about 35 deaths to the 151.) This could mean that only about 1/3 of the people are savable at the time the alarm is turned in.

1 Note that fires between 0800-1100 and 2000-2400 are excluded.
R8-9

Abstract: The toxicity index for a material is the sum of the indices for each of its combustion products. The index for a product is the ratio of the concentration of the product that results from burning one gram of the material and diffusing the combustion products in one cubic mm of air to the concentration of that product that is fatal to man in 30 minutes exposure. For the denominator, some fatal concentrations have been inferred from animal experiments; others can be guessed; others need animal experiments and theoretical calculations. As the authors point out, an important factor omitted from their index is the rate at which combustion products are produced. They say that typically the air in a burning room turns over rapidly, "one complete air change ... in about one minute." If the burning rate were available, they indicate that concentrations in the room in question and its neighbors could be predicted.

Issue: Can theoretical toxicity calculations for materials, made from knowledge of the combustion and lethal concentrations of chemical products, be used to regulate their use in buildings?

Policy Utility: Awaits determination of whether the authors' toxicity index is a useful predictor of fatality and injury in real fires.

Validity: Needs predictions of rate at which combustion occurs in order to see if actual concentrations are proportional to their index. After that, there is the question of how reliably the concentrations are associated with casualty.

R8-10

Abstract: From data on 570 patients, the authors develop a model for predicting chance of survival using the age and sex of the patient and the body surface burned. Other factors considered were race, part of the body burned, type of burn, and whether a tracheotomy was performed. They were not significant. The results of the model are two tables (one for men, the other for women) and a graph, so no calculation is required by the user. Although there are two tables, careful inspection reveals no difference between men and women that is worth noting. That is, for a fixed age and burn extent, the predicted chance of survival for men is always well within one percent of the predicted chance for women.

Audience: Everyone.

Issue: How is the chance of burn survival affected by various factors (age, extent of burn, etc.)?

Policy Utility: Possibly useful for evaluating how well a small medical unit (say a hospital) cares for its burn patients. Such a unit's experience is a compound of the savability of its patients and the quality of the care it furnishes and can be hard to judge if it sees few cases. The discriminant procedure can remove the effect of savability, making it possible to assess the care effect.

Internal Validity: Adequate.

External Validity: The data were collected over a period of years, and changes in treatment may affect the attainable chance of survival.

R8-11

Abstract: Step-wise multiple regression is used to analyze the survival time of a group of people who suffered and eventually died from burns. (The group was all such people in Ontario from 1954 to 1963, 199 in all.) The explanatory variables used were the age and sex of the victim, the fraction of the body surface burned, and the year and month the burn occurred. Women, young people, and those with less extensive burns survive longer. (For example, the author estimates an average survival time of about 40 days for a 30-year-old woman with a 20 percent burn, but less than two days for a 70-year-old man with an 80 percent burn.)

Audience: Researchers, fire professionals.

Issue: What influences burn survival time?

Policy Utility: Slight, since it looks only at survival time of those who do not survive. If we knew how fire protection decisions were related to burn severity etc., then knowing how severity influenced the chance that a burn victim survived would be interesting.

Validity: Given the low policy utility, the question of validity is irrelevant.

R8-12

Abstract: A procedure for “analyzing the various aspects of fire safety in housing” is developed in this paper and applied to an example fire. The framework tries to include “all the physical and behavioral data as well as the relevant concerns and issues of fire safety.” Elements of the procedure are: “a description and morphological analysis of the setting; a mapping of fire-related
events, including the behavior of those involved in and around housing subject to fire; an evaluation of the fire situation against a set of concerns related to fire safety and a set of fire safety areas; and, finally, the production of fire-related issues and arguments, leading to fire safety standards, heuristic principles, and directions for future research."

**Audience:** Architects, fire professionals, fire chiefs.

**Issue:** How can life safety in a building be improved?

**Policy Utility:** Medium. You need a real breakthrough to justify the large number of concepts and the complexity of the mappings. Their framework is interesting, but not a breakthrough. The concepts are too numerous for the insights and focus provided. The paper is instructive reading for anyone who wants to think about a comprehensive approach to fire safety, and it provides needed encouragement for architects to think about the fire problem. However, it is dense with abstract terms (morphology, holistic, heuristic, etc.) that may deter the nonacademic reader.

**Internal Validity:** Adequate. There are no findings to be judged and no methodology to be evaluated.

**R8-13**
I. N. Einhorn and J. H. Petajan, "Smoke and Survival During Fire Exposure," Flammability Research Center, University of Utah, Salt Lake City, Utah, n. d.

**Abstract:** The paper presents a detailed review of what is known about the effects of the products of combustion on humans and animals. It also describes the author's extensive experiments on the effect of carbon monoxide on rats.

The list of effects is long, ranging from smoke obscuring vision directly and causing tears, to respiratory damage, to carbon monoxide poisoning, to possible neuromuscular and other effects of other toxic combustion products. The need to consider all factors in realistic situations is stressed, while the difficulty of doing so is apparent.

**Audience:** Researchers.

**Issue:** What effects does smoke have on people?

**Policy Utility:** Useful for background and as indication of where there might be leverage for preventing deaths. It also reveals the great distance between animal experiments and public policy implications.

**Internal Validity:** Adequate. One exception—they mention that a group of 105 fire fatalities had less than 40 percent body surface burns and that 77 percent of them could have been expected to survive. The 77 percent comes from work such as McCoy, Micks and Lynch (R8-10). But since the group of 105 consists only of fatalities, the 77 percent figure is wrong.

**External Validity:** Adequate.

**R9-1**

**Abstract:** In this brief note, the author uses data developed by Dunn and Fry (1966) on 1,210 large loss fires in the United Kingdom. In 376 of these fires there was no delay in detection, in 689 fires there was a delay, and in the remainder it is not known whether there was a delay. The author ignores fires in the last category and calculates that

\[
\frac{376}{376 + 689} = .353
\]

is the probability that a fire becomes large if there is no delay. Hence roughly 689 (1 - .353) or about 440 fires might have been prevented from becoming large through the use of detectors. Since large loss fires cause about £50 million in damage per year, the potential savings is about £20 million per year.

**Audience:** Everyone.

**Issue:** The effectiveness of early detection systems.

**Policy Utility:** Useful, since it gives an estimate of maximum savings. However, this back-of-the-envelope calculation illustrates how little is known about detection effectiveness.

**Internal Validity:** The results are somewhat misleading. Fires that do not become large loss fires are smaller loss fires, not zero loss fires. Actual savings depend on the magnitude of these smaller loss fires.

**R9-2**

**Abstract:** Data are presented showing more large fires at night. The author then discusses the use of detectors and the tradeoff between having many false alarms and not detecting fires quickly enough. The author cites studies that show over 90 percent of detector calls are false. He points out that the causes of false alarms seem to be related to testing and installation and discusses some guidelines for installation.

**Audience:** Researchers, fire professionals.

**Issues:** (1) How effective are detectors? (2) The detector false alarm problem. (3) How should detectors be placed?

**Policy Utility:** Medium. Paper is mostly a think piece.

**Internal Validity:** Data from Bavaria and England show that there are more large fires at night than during the day. The author quotes Rasbash (1974) as saying that if widespread use of detectors reduced the probability of a fire becoming large to the minimum value occurring in the day, about 60 million dollars a year could be saved in the United Kingdom. The assumption that differences in the probability that a fire becomes large are
due entirely to delayed detection is questionable. During working hours, there are fires caused by people. These fires may be less serious, given equal detection time, than fires that occur in the middle of the night.

R9-3

Abstract: In this paper the author addresses three subjects: (1) the comparative response times of various fire detectors; (2) the spread of fire with and without detection devices; and (3) fire losses in fully sprinklered buildings, buildings with automatic detectors, and other buildings.

Audience: Everyone.

Issues: The effectiveness of sprinklers and automatic detection systems.

Policy Utility: Some. At best the paper suggests that losses are lower in sprinklered buildings than in buildings protected by automatic detectors.

Internal Validity: Questionable.

External Validity: Questionable.

Summary: The paper is divided into three main sections dealing with discovery delays, fire spread, and monetary losses associated with sprinklers and fire detectors.

The first section is made up of extracts from previously published papers reporting response times of various fire detectors and sprinklers in several fire environments. The tests, conducted in the U.S. and Europe, all point to the conclusion that smoke detectors respond faster than heat detectors and heat detectors respond faster than sprinkler heads.

Apparently, the author uses the detector response information from the first part of the paper and estimates of fire company response time to construct curves which show the proportion of fires which would have been reached by the brigade before becoming fully developed in each of the types of area (a), (b), and (c), assuming (1) a time of between 5 and 20 minutes for full development, (2) an automatic heat detector head of the most sensitive type permitted by British standards, and (3) a direct link from the detector head to the fire brigade H.Q.

Areas (a), (b), and (c) refer to "rural county," "nonrural county," and "county borough," respectively. These would seem to correspond to rural areas, suburbs, and cities. The term fully developed is defined to be a fire that has reached flashover with all combustible surfaces alight in room of origin.

The author estimates that for fires that fully develop in five minutes, 0 percent, 50 percent, and 55 percent would be reached by the fire brigade within that time for rural county, nonrural county, and county borough. For fires that fully develop in 10 minutes, the figures are 40 percent, 93 percent, and 100 percent. For fires that fully develop in 20 minutes, the figures are 87 percent, 100 percent, and 100 percent. The author states that the significance of these figures "lies in the indication it gives that about half of even the most rapidly developing fires would be reached and fought by the brigade before flashover in response to an automatic alarm, in county borough and nonrural county areas."

The purpose of the last part of the paper is to compare losses in unprotected buildings, sprinklered buildings, and buildings with automatic detection systems devices linked directly to the fire brigade. To this end, the author has compiled data on fires in industrial and distributive trades buildings (excluding agricultural, forestry, construction, and fishing industry buildings) in the period 1961-1966 that resulted in fire damage of £40,000 or more. The data show that the chance that a fire in a fully sprinklered building causes more than £40,000 damage is 1 in 195. In a building with automatic detectors linked to the fire brigade, the chance is 1 in 93, while for industrial and distributive trades buildings as a whole, the chance is 1 in 65. These data are compared with data presented by Dunn and Fry (1966), who examine the period from June 1962 to December 1964. Dunn and Fry also consider industrial and distributive trades buildings and are concerned with fires fought with five or more jets (this probably means hose streams). The estimated damage from these fires is roughly £20,000 or more. The corresponding results are 1 in 270 for fully sprinklered buildings, 1 in 100 for buildings with automatic detectors linked to the fire brigade, and 1 in 45 and industrial and distributive trades as a whole (including the agricultural and construction industries). The author concludes with descriptions and loss estimates for each fire with damage over £40,000 in sprinklered buildings and buildings protected by detectors, during the period 1961-1966. There were 32 such fires in sprinklered buildings and 17 in buildings with detectors. He finds that the average losses were £135,700 for sprinklered buildings and £250,400 for automatic alarm-protected buildings.

Discussion: The section on fire spread and brigade arrival times is not documented well and does not lead anywhere. The data presented on losses need to be viewed with caution. For example, the author's figures imply that the chance of a large fire in an unprotected building is 1-1/2 times greater than in a building with automatic detectors and three times greater than in a sprinklered building. However, there may be differences in the percentage of fires that are reported to the fire brigade. For example, in buildings with detectors, some of the fires are minor but are automatically reported. In unprotected buildings, the same type of fire might be extinguished using a fire extinguisher and not reported. In comparing the average losses in sprinkler-protected buildings and detector-protected buildings, the au-
R9-4


Abstract: The authors have examined the circumstances surrounding 342 fires that resulted in loss of life in residential "unshared separate dwellings" in Ontario between 1956 and 1960. The authors subjectively estimate the likelihood that each victim would have been saved if (1) a smoke detector had been present and (2) a heat detector had been present. They estimate that smoke detectors would have saved 41 percent of the victims and heat detectors would have saved 8 percent.

Audience: Researchers, private home owners, fire professionals.

Issue: Effectiveness of detectors.

Policy Utility: High.

Internal Validity: Adequate.

External Validity: Care must be taken in attempting to extend these results to other situations, although the methodology would be useful.

Summary and Discussion: The data available to the authors included: year of occurrence, construction of wall and ceiling linings, age of victim, cause of fire, and physical state of the victim (or responsible adult if victim was a child or infant). With this information the authors attempted to make a subjective estimate of the likelihood that the victim would have been saved given the presence of one of the two fire detection devices. The likelihood was rated on a scale from 0 to 100 with five possibilities allowed: 0, 25, 50, 75, and 100. The two types of detectors considered were (1) a fixed temperature device with a small thermal-capacity/surface-area ratio, and (2) a very sensitive ionization chamber smoke detector. Moreover, the authors assumed that the fixed temperature devices had been installed at the head of every staircase and in the room of origin of the fire. Two smoke detectors are assumed to have been installed at the head of the basement stairs and the head of the main staircase in a two-story building or between the living and sleeping areas in a one-story building.

On a percentage basis, smoke detectors are about five times as effective as thermal detectors in saving lives. The average likelihood for smoke detectors was about 41, about 8 for thermal detectors, and appears to be invariant with respect to wall and ceiling construction. (As the authors point out, this does not imply that the saving of life per 1000 installed devices is independent of the wall and ceiling construction.)

Of the 342 deaths investigated, 92 percent were associated with fire originating in an area other than the basement, 3 percent with fires originating in basements, and 2 percent of unknown origin. But the authors give no information as to the effect of this characteristic on the likelihood that the victim could have been saved. About 26 percent of the incidents fall into the following categories: improper use of flammable liquids, falling asleep while smoking, and intoxicated. A low likelihood rating was usually associated with these fires.

A breakdown of the likelihood ratings as a function of whether or not the victim or responsible adult was asleep suggests that smoke detectors would decrease the death risk for sleeping victims by about 60 percent, and thermal detectors by about 12 percent. For victims not asleep, the likely decreases for each detection device are about 13 percent and 1 percent. One might expect or at least hope that the rating for sleeping victims would be higher than 60 percent. Part of the reason for the low rating here is that about 34 percent of these incidents are in the categories of "fall asleep while smoking" or "intoxicated," and in view of the results reported in the previous paragraph the low rating here is not surprising. Nor is it surprising to see such large differences between the ratings of the two devices since the authors point out that this is a function of their operating characteristics. To be detected by the thermal device, a fire must generate a temperature of 150° or more in the area around the device. The victim could have died of smoke inhalation long before this.

The validity of the work in this paper rests mainly on the validity of the author's subjective likelihood ratings. Assuming the rating scheme is valid, enough data have been examined to give a reasonable amount of confidence in the likelihood ratings. However, no estimates of the variance of the estimates are given, and significant differences in the estimates are not tested.

R9-5


Abstract: This paper presents fatality statistics in dwelling fires, describes household fire protection devices, and presents figures on costs and potential benefits.

Audience: Everyone.

Issues: The costs and benefits of fire detection systems.

Policy Utility: High, since it makes the point that household detection systems can cause significant reductions in fire fatalities and suggests what kinds of efforts would lead to increased use of detection systems in the home.

Internal Validity: Nothing much quantitative to
check since all the statistics or estimates seem to have been extracted from previously published material. Reasoning is logical.

**External Validity**: Not applicable.

**Summary**: The first third of the paper is a review of fatality statistics for dwelling fires in the United States during the 1960s. This part of the paper also covers operational principles of fire detection devices and various combinations of these devices that constitute household fire detection systems. The important point of this section is that something like 70 percent of fire fatalities occurred in dwellings and 57 percent of the victims were asleep at the time of the fire, indicating that early detection devices in dwellings would have a major effect in reducing loss of life.

The middle third of the paper is devoted to a history of the production costs of household detection systems. The statistics are summarized in a table in which the author gives the 1966 and 1971 estimated U.S. production and 1971 approximate costs of the various residential detection systems. The important points of this section of the paper are, evidently, that probably less than 1 percent of the estimated 63.5 million households in the United States in 1971 were protected by some form of fire detection system, and that a likely factor leading to this low percentage is the estimated $375 to $2000 installation cost of complete household protection systems (includes at least one smoke detector and ten heat detectors). Even the cheapest single station device (portable and containing both an alarm and a detector) runs from $22 to $70 and affords protection only in the immediate vicinity of the detector.

Finally, the last third of the report addresses the problem of cost vs. life-saving potential of household detectors. Based on the report by McGuire and Ruscoe (R94), the author estimates that a saving of one life per year could be effected by protecting 18,000 additional households. Hence, any significant reduction in dwelling fire deaths would be achieved only through widespread installation of home fire detectors. This, in turn, would seem to require a nationwide push for the installation of household fire detectors. However, as the author points out, a reduction in the cost of such detectors would make any program to push them that much more successful. A substantial part of the cost of complete detector systems is due to installation fees; hence, research aimed at making these systems simple to install may lead to significant cost reductions.

R9-8

**Abstract**: This report concerns an automatic early detection and warning system (EDWS) for fires in buildings. Use of this concept could significantly improve citizens' safety by greatly reducing the critical time interval between the start of a fire and the arrival of firemen and equipment. The report describes the basic concept of an EDWS, examines the costs and some of the potential effects of the system, and discusses first steps that could be taken to assess the desirability of widespread implementation.

**Audience**: Everyone.

**Issues**: The costs and benefits of fire detection systems.

**Policy Utility**: Medium. It suggests the potential benefits of an EDWS and recommends useful future work.

**Summary**: This report describes an early detection and warning system (EDWS) for fires in buildings and examines the technological and economic feasibility of its widespread installation in New York City. The New York City Fire Department shares with other major urban fire departments a problem of rapidly increasing numbers of alarms and fires; many of these are fires in buildings, which threaten and destroy life and property. The problem of loss of life due to fire is particularly frustrating, since the early minutes of a fire may be the most crucial, yet the fire department cannot know its services are needed until someone notices the fire and reports it appropriately. A potential solution is suggested involving the automatic detection of incipient fires and automatic transmission of alarms and alarm information directly to the fire department.

The authors find that a large-scale EDWS using ionization (combustion product) detectors is technologically feasible, and its likely cost can be estimated. The magnitude of present and future fire losses and the number of those fire losses that can be saved are uncertain. This uncertainty prevents a definite statement of economic feasibility from being made. However, the potential benefits of an EDWS appear great enough to warrant further consideration of the system.

Further study of an EDWS should center on two areas: fire losses and EDWS operational characteristics. A study of fire losses, important for establishing definitive EDWS feasibility, could also help in guiding fire department preventive and fire-fighting operations.

The operational characteristics of an EDWS and its interaction with existing institutions should be examined in two phases: a preliminary data-collection phase using existing detector installations and an experimental phase involving a carefully designed pilot program. Concurrently, implementation studies should begin. These studies should address problems connected with system design, installation, and use as they are affected by the social and political realities of life in New York City.

R9-7
E. D. Chambers, Failure Rates of Automatic Fire Detection and Alarm Systems, Fire Research Note No. 932,

Abstract: The author analyzed 460 fires in Great Britain in 1968 in premises equipped with automatic fire detection systems. In about 3.5 percent of the cases, the system failed to alert the fire department but gave a local alarm. In about 1.7 percent of the cases, the system failed to give any alarm. About half the failures were due to the disconnection of the system and 38 percent were due to faulty equipment.

Audience: Researchers, consumers, fire professionals.

Issue: Estimating the failure rate of automatic fire detection systems.

Policy Utility: Some, but the important question—detector effectiveness—is not addressed.

Internal Validity: Questionable; the author assumes that the detector was operable in all instances where a person turned in the alarm before the detector. This is not necessarily true.

R9-8


Abstract: Essentially an information piece designed to acquaint the reader with the various detection systems available and their limitations. Stresses laboratory listed equipment and proper installation and maintenance procedures.

Audience: Mainly consumers.

Issue: The costs and effectiveness of detectors.

Policy Utility: High. Required reading for consumers interested in fire detection equipment.

Internal Validity: Not applicable.

R9-9


Abstract: Discussion of the principles on which smoke and ionization detectors are based; considerations in choosing the best detection devices and their proper installation as a function of their operating characteristics. It is worthwhile mentioning that the author claims that Underwriters' Laboratories, Inc. recommends a "completely unrealistic" spacing between smoke and ionization detectors. U.L. Inc. recommends spacing not to exceed 3600 sq ft per detector; the author says it should not exceed 1000 sq ft under any conditions.

Audience: Applications engineers.

Issue: Design of fire detection systems.

Policy Utility: Low. The audience primarily consists of detection system design engineers. Needs some cost and effectiveness discussion to have policy implications beyond installation standards.

Internal Validity: Not applicable.

R9-10


Abstract: Discusses the relative effectiveness of smoke and heat detectors and some dos and don'ts about their installation. Cautions that since most fire fatalities are caused by asphyxiation or anoxia, heat detectors are not sufficient protection. Suggests that, since some home fires are caused by gas leaks, full protection should include gas detectors. Reminds us that detectors can reduce life loss only if we get the homeowner to install and maintain them, and then make sure he knows what to do after the alarm operates.

Audience: Everyone.

Policy Utility: Aside from the good point that full fire protection might include gas detectors, the paper does little more than to serve as a reminder, to people in fire protection, about problems they should already be aware of. The consumer, perhaps, would derive some utility.

Internal Validity: Not applicable.

R9-11


Abstract: The paper begins with a brief discussion of current fire detection systems and the most hazardous aspects of building fires. Compartmentation and ventilation are currently, for the most part, achieved by heat-sensitive devices on doors and dampers in ducts penetrating fireproof partitions. Ventilation of stairwells is probably initiated manually. The author suggests using smoke detectors also for the closing of doors and dampers or at least using the fire detection system to shut off all mechanical ventilation and initiate escape-stairwell ventilation. He then goes on to describe some ("extravagant") schemes that would let escapees know the best route for vacating the building, also initiated by the fire detection system.

Audience: Consumers, engineers, fire professionals.

Issue: The effectiveness of fire detection systems.

Policy Utility: Potentially high because of the issue involved, but low because the author does nothing to resolve the issue.

Internal Validity: Not applicable.
R9-12

Abstract: This paper discusses fire types and the products that they produce, detector response time, and operating characteristics of various detectors. It has some discussion of installation standards and contains some interesting ideas about adapting devices that are currently being used in other fields for fire detection. A long reference list of detector-related literature is given. The author recommends standardized test procedures to rate the various detector types according to response time and frequency of false alarming. This may be a difficult task considering the many types of fires and the operational differences in the detectors. There is also a need for increased research and development of fire detectors (presumably aimed at reducing the cost of detection systems; rapid detection does not seem to be an issue if cost is ignored).

Audience: Researchers, fire professionals.

Issues: Operational characteristics of fire detectors under different test conditions.

Policy Utility: Useful to policymakers interested in building codes, but it lacks a cost analysis.

Internal Validity: Not applicable.

R9-13

Abstract: Detailed discussions on the following subjects related to fire detectors: detecting products of combustion; psychological and physiological effects in humans exposed to these products; operating characteristics by which detectors are classified; the types of fire detectors and the physical principles upon which they work; detector subsystems, such as alarm and breakdown alerting circuits; effects of heating and air conditioning units on detector response; detector response changes due to background levels of products usually associated with fires; reliability, maintenance, performance standards, and field tests of detection devices; some trends in federal, state, and local building code requirements for fire detectors. There is a fairly complete bibliography of current fire detection literature. The authors note that it is possible, though not always cost effective, to provide nearly any level of response with current detection technology. False alarms are still a problem, and a promising approach is to use multimode detectors requiring signals from several products produced by fires to initiate the alarm. There is a need for a universal standard for testing the performance of detectors under a wide range of fire situations.

Audience: Researchers, research funders, fire professionals.

Issues: A range of topics relating to the use of fire detectors.

Policy Utility: Anyone involved in fire protection, from engineers to policymakers, should find at least one section of this work interesting. The utility to policymakers, however, would be far greater if the authors had provided some examples of how the various devices can be combined into a system that would provide effective protection in specific situations (e.g., building construction, occupancy) and approximately how much each system would cost. Without a cost and effectiveness discussion, it is impossible to know how far to go with installation standards since the standards may imply a detection system of prohibitive cost.

Internal Validity: A generally thorough review of the subject.

R9-14

Abstract: This paper begins with a discussion on the likely savings to be realized in the United Kingdom from automatic detection systems, their past performance record, and some fundamental factors to be considered when deciding what type of system, if any, should be installed. The section entitled Reliability of Equipment is intended to be the main contribution of the paper.

Audience: Fire protection engineers.

Issues: The effectiveness of automatic detection systems.

Policy Utility: Low, because of lack of internal validity.

Internal Validity: Very poor. The calculations of detector reliability are wrong. The author confuses the probability of an event and its expected value.

R9-15

Abstract: The 45,000 fires in dwellings in the United Kingdom in 1969 are analyzed. Those fires attacked by the dwelling’s occupants using fire extinguishers (1,318 fires) and using “sundry” means (20,338) and those not attacked are compared. The sundry means included “buckets; smothering; garden hose;” etc. Of those attacked by sundry means 43 percent were out before the brigade arrived; 27 percent of those attacked using extinguishers were put out before its arrival. The ones
fought by sundry means took the brigade 6.5 minutes to control, and the ones fought with extinguishers needed nine minutes. The ones not fought at all by occupants took nine minutes to control.

**Audience:** Everyone.

**Issue:** What is the value of home extinguishers?

**Policy Utility:** Low, but the problem is important.

**Internal Validity:** Weak. The authors indicate that the choice on the part of dwelling occupants of whether to attack the fire may depend on the character of the fire. But it may also depend on whether an extinguisher is available. How often one was available but ignored in favor of sundry means or no attack at all was not recorded. Nor is it known how often no extinguisher was available, and in those cases, whether it would have been used in preference to sundry means or no attack. Consequently, one cannot forecast from the data here what would happen if extinguishers were more widely available.

**R9-16**


**Abstract:** Since 1897 the National Fire Protection Association has maintained records on fires in which sprinklers operated. Tables are given in both reports covering satisfactory sprinkler performance, number of heads opening, occupancy, and a classification of unsatisfactory performance.

**Audience:** Fire protection engineers, researchers.

**Issue:** Sprinkler effectiveness.

**Policy Utility:** Some, but the data are mainly of interest to design engineers, not those interested in the costs and benefits of sprinklers.

**R9-17**


**Abstract:** Detailed information on fires in sprinklered buildings in Australia and New Zealand is presented in this book for an 82-year period beginning in 1886. The author hopes that this information can be "used as the basis for informed judgment on matters which are of great importance in regard to the construction and occupancy of modern buildings." He addresses such subjects as requirements in tall buildings, smoke and heat venting, and effectiveness for life safety.

**Audience:** Fire protection engineers, fire professionals, researchers.

**Issues:** Sprinkler effectiveness, costs and benefits.

**Policy Utility:** Low for policymakers, higher for design engineers.

**Internal Validity:** Inadequate. Data sources are not documented sufficiently; meaningful measures of sprinkler performance are not developed, and the cost-benefit analysis is not substantiated.

**Summary:** This book provides information on 5,734 fires in Australia and New Zealand in which sprinklers were activated during the period from 1886 to 1968. The chapters cover the following subjects: a glossary of terms; a history of sprinklers in buildings in Australia and New Zealand; technical aspects of water discharge; overall performance analysis as well as analyses by occupancies, life safety; causes of fires; incendiaryism, flammable liquids fires, electrical fires, explosions, fires involving high-piled storage; exposure fires; smoke and heat venting in relation to sprinkler performance; fires in which a large number of sprinkler heads operated; fires in partially sprinklered buildings; fires involving multiple-jet controls; fires with unsatisfactory sprinkler performance; and cost-benefit analysis. The author defines satisfactory sprinkler performance as "performance where after the fire has been extinguished, the building has suffered only minor damage, and the loss of contents through fire, water and smoke is a relatively small proportion (say of the order of not more than 20 percent) of the total value involved."

Some of the major findings are:

- Sprinklers were operated in a satisfactory manner in 99.76 percent of the fires.
- Fires were controlled by 10 or fewer sprinkler heads 96.7 percent of the time (the U.S. figure was 85.4 percent).
- Data by occupancy showed:

<table>
<thead>
<tr>
<th>Occupancy Group</th>
<th>Number of Fires</th>
<th>Satisfactory Percent</th>
<th>Average Number of Sprinklers in Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>55</td>
<td>100</td>
<td>1.3</td>
</tr>
<tr>
<td>Assembly</td>
<td>40</td>
<td>100</td>
<td>1.8</td>
</tr>
<tr>
<td>Educational</td>
<td>10</td>
<td>100</td>
<td>2.1</td>
</tr>
<tr>
<td>Institutional</td>
<td>55</td>
<td>100</td>
<td>1.2</td>
</tr>
<tr>
<td>Offices</td>
<td>130</td>
<td>100</td>
<td>1.4</td>
</tr>
<tr>
<td>Mercantile</td>
<td>886</td>
<td>99.77</td>
<td>2.3</td>
</tr>
<tr>
<td>Industrial</td>
<td>4484</td>
<td>99.77</td>
<td>2.8</td>
</tr>
<tr>
<td>Storage</td>
<td>31</td>
<td>96.7</td>
<td>3.9</td>
</tr>
<tr>
<td>Other</td>
<td>41</td>
<td>95.12</td>
<td>2.4</td>
</tr>
</tbody>
</table>

- Of the 110 fires occurring in residential and institutional occupancies, only one fatality occurred.
- Of the 120 cases of incendiary fires in sprinklered premises, the fires were either extinguished or controlled in every instance.
- In electrical and flammable liquids fires, the sprinklers were effective in almost all cases.
During severe explosions, the sprinkler system becomes too damaged to operate effectively. In smaller explosions, though, sprinklers were effective.

- In partly sprinklered buildings, sprinkler performance was generally unsatisfactory.
- In fully sprinklered buildings, unsatisfactory performance occurred for one or more of the following reasons: severe external exposure, explosions, severity of internal hazard, inadequate water supply, or other factors (roof flammability, for example).

The last chapter is devoted to a cost-benefit analysis of sprinklers. Using data from the period 1948-1967, the author estimated fire losses plus water leakage damage in sprinklered buildings to be about $6.7 million (Australian dollars). The author adds to this estimates of interest on capital invested, depreciation, and maintenance cost. He states, "Unfortunately, figures are not published for any of these items, but from personal observation it is unlikely that the total would exceed 1.5 million dollars per annum." Thus, the total cost is estimated to be about $36.7 million for the 20-year period. These costs are then compared with the estimated fire losses in these buildings if sprinklers had not been installed. Using records for 1967 on fires in industrial, commercial, and institutional buildings not equipped with sprinklers, the author finds a range of losses from $3,000 to $2,000,000, with an average of about $100,000. He states, "It would seem reasonable to take approximately half of this figure or, say, $50,000 per fire as a conservative estimate of the potential losses had sprinkler systems not operated in the buildings concerned." Multiplying this figure by 3,781, the total number of fires involving sprinklers, he gets a total of about $188 million. The estimated savings over the 20-year period therefore are approximately $151 million.

**Discussion:** Although this book contains a wealth of information, it is mainly of interest to design engineers. The book suffers from a number of weaknesses. The data sources are not sufficiently documented. For example, it is not clear what proportion of the total number of fires involving sprinklers is represented by the 5,734 fires or how this sample was chosen. The definition of satisfactory sprinkler performance is arbitrary, imprecise, and therefore not adequate. Further, the author does not give comparable figures for buildings without sprinklers. That is, in what percentage of all fires is damage to the building minor and damage to contents less than 20 percent? This number is clearly very high—i.e., a very small fraction of all fires (involving sprinklers or not) are serious. Finally, the cost-benefit analysis is not substantiated. Although the author acknowledges that his analysis is "limited," it is not sufficient for policymakers who are concerned with the costs and benefits of sprinklers. The cost figures are not justified, nor is the figure of $50,000 used as the average loss per fire in buildings not protected by sprinklers. The average damage in the fires involving sprinklers was $1400.

**R9-18**


**Abstract:** "Statistics of the number of sprinkler heads opening in fires are used to investigate the influence of various factors on sprinkler behavior." Factors considered are the age of the sprinkler system and whether it is a wet or a dry one.

**Audience:** Fire protection engineers, researchers.

**Issue:** Sprinkler effectiveness.

**Policy Utility:** Low for policymakers, possibly higher for fire protection engineers.

**Internal Validity:** The necessary assumptions were not explicitly made, but manipulation was well done. The data were not adequately discussed.

**External Validity:** Agrees with the U.S. results published by the National Fire Protection Association.

**Summary:** The number of sprinkler heads opening is a measure of fire size and water damage. By using statistical (regression) techniques, the authors compute cumulative frequency distributions for the number of sprinkler heads opening in fires in sprinkler-equipped buildings. They perform the computation for both U.K. and U.S. data and find the distributions quite similar. The authors use the same methods for examining sprinklers in large loss (>$10,000), medium loss ($1,001-10,000), and low loss ($1-1,000) fires. The results reflect the tendency for more sprinklers to open in larger loss fires.

The hazard group was considered as a factor in the number of heads opening and in the percent of fires controlled by the sprinklers. Using English sprinkler design criteria, the authors computed the maximum number of sprinklers expected to open in a fire. This number ranged from four in extra light hazards to 29 in extra heavy hazards. Using data on actual fires, they found that the maximum number of heads expected to operate was exceeded more often for lighter hazards (23 percent of the fires for extra light) than for heavier hazards (3 percent of the fires for extra heavy). The authors also calculated the percent of fires controlled in each occupancy group, given that the system worked at all. The results are:

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Number of Fires</th>
<th>Maximum Expected Number of Heads</th>
<th>Percent of Fires Maximum Exceeded</th>
<th>Percent of Fires Controlled by Sprinklers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra light</td>
<td>30</td>
<td>4</td>
<td>23</td>
<td>90</td>
</tr>
<tr>
<td>Ordinary-1</td>
<td>8</td>
<td>6</td>
<td>17</td>
<td>88</td>
</tr>
<tr>
<td>Ordinary-2</td>
<td>91</td>
<td>12</td>
<td>9</td>
<td>93</td>
</tr>
<tr>
<td>Ordinary-3</td>
<td>476</td>
<td>18</td>
<td>6</td>
<td>95</td>
</tr>
<tr>
<td>Extra heavy</td>
<td>14</td>
<td>29</td>
<td>3</td>
<td>79</td>
</tr>
</tbody>
</table>
Using age of the building as a proxy for age of the sprinkler system, the authors found that fewer heads were released in fires in older buildings, and, if the system worked at all, a greater percentage of the fires were controlled.

A "wet" system has pipes that are normally filled with water. But when there is a risk of freezing in unheated buildings, a "dry" system (one in which the pipes are fitted with air under pressure) is used. Using American (NFPA) data and a regression technique similar to the one used to compare U.S. and U.K. data, the authors found, on the average, twice as many heads open in dry systems as in wet systems. The authors present statistical models to try to explain the better performance of wet systems. The size of the fire at the time of sprinkler activation is in part a function of the activation delay of the sprinkler system. Dry systems have a longer delay.

R9-19

Abstract: A survey was undertaken in 1965 to estimate the frequency of sprinklered premises in different occupancies and in different industries. Fire brigades reported both the number of sprinklered premises and the number having full and effective protection. Warehouses and factories were found to have the most sprinklers installed. Except for offices, sprinklers were installed effectively in at least 95 percent of the premises.

Audience: Researchers, fire professionals.

Issues: Extensiveness of sprinkler installations in England.

Policy Utility: The results of this paper are used to estimate sprinkler expenditures (see R9-20).

Internal Validity: Good. The sampling problems are treated well.

R9-20

Abstract: "In this paper an estimate has been made of the total expenditure on sprinkler installations in the United Kingdom in comparison with other forms of fire protection in buildings. A national expenditure of the order of £34 million on sprinklers is indicated for the year 1970 out of an estimated total of £80 million towards all forms of fire protection in buildings in that year."

Audience: Researchers, fire professionals.

Issues: National expenditure on sprinklers vs. other forms of fire protection.

Policy Utility: Low, since the author does not do anything with his estimates, although they could be useful input to another study.

Internal Validity: Since the data sources were indirect, a number of assumptions and manipulations had to be made to get the number of sprinklered vs. unsprinklered buildings, the average size of the newly sprinklered buildings, and all costs. Ramachandran did a sensible job of estimation.

R9-21

Abstract: The paper deals with the issue of charges for water supplied to fire protection systems. These charges could needlessly hinder installation of sprinklers, standpipes, etc. A survey was made of 95 cities with populations over 20,000 as to water charges and water connection requirements.

Audience: Researchers, city administrators, fire professionals.

Issue: Sprinkler costs.

Policy Utility: Potentially high. City managers should be interested to see how other cities handle water charges. However, the author did not go far enough in making the point about the doubtful necessity for water charges.

Internal Validity: Adequate.

External Validity: Good. Work is based on a survey of a large number of cities.

Summary and Discussion: This is a student paper in a fire protection course given by Professor John Bryan. The author wants to assess the types of water charges that exist for fire protection installations (sprinklers) and how these charges affect investment decisions in sprinklers. The most expensive part of water charges is not the cost of the water but the cost of the equipment building owners must buy to allow water use to be monitored.

The author sent questionnaires to 129 cities with populations of over 20,000, and received 95 responses. He found that water meters were required in many buildings in 60 percent of the responding cities, and that meter pits are required in 76 percent of the instances where meters are required. ("A meter is an instrument which measures water flow through a pipe. A meter pit is a shelter for the protection of meters from weather and vandalism.") These meter requirements add $4,500 to over $5,000 to the cost of sprinkler systems. And in
many cases, water departments charge for the existence of a sprinkler or standpipe system connection (up to $1,000) as well as the charge for the metered water. Although water meter costs should affect the degree of sprinkler use, the author was not able to prove the existence or extent of disincentives provided by meter costs. He makes the point that if a fire occurred in a building without sprinklers or standpipes, more water would probably be required for extinguishment. (Often, this water is free.) What he does not mention is that water supply departments may be more concerned about tapping of domestic water from fire lines than water used for fire extinguishment.

R0-22

Abstract: The authors present a model in which total fire losses are minimized with respect to installation of "passive" fire protection and "active" fire protection. Active protection means sprinklers. Passive protection refers to fire-resistant structural characteristics. Possible alternatives are to install one, the other, or a combination of passive and active protection.

Audience: Fire researchers.

Issues: Sprinklers vs. other private protection.

Policy Utility: Low, unless estimation of the model's parameters could be made.

Internal Validity: The model is well done, assumptions are explicitly made.

External Validity: In order to use the model, one must estimate: (1) probability of sprinkler failure; (2) cost of the sprinkler system associated with that probability of failure; (3) probability of fire-resistance (construction) failure; (4) cost of that construction with that probability of failure; (5) expected losses if neither sprinklers nor fire resistance fails; (6) expected losses if only sprinklers fail; (7) expected losses if only fire resistance fails; (8) expected losses if sprinklers and fire resistance fail. These figures are probably impossible to estimate accurately.

R10-2
E. Ignall et al., "Improving the Deployment of New York City Fire Companies," The New York City-Rand Institute, P-2280, July 1974; also in Interfaces, Vol. 5, February 1975, pp. 48-61.

Abstract: How many fire companies does New York City need and where should they be located? Given a fire alarm of unknown severity, how many companies should be dispatched to it? Since 1968, the New York City Fire Department and The New York City-Rand Institute have carried out a joint project to improve the delivery of Fire Department services in the face of skyrocketing demand. In November 1972, two important deployment changes were implemented: Six of the city's 975 fire companies were disbanded and seven were permanently relocated. In high fire incidence areas, an adaptive response policy was implemented under which fewer companies are initially dispatched to potentially less serious alarms. The project, the analyses that led to these and other improvements, and the mathematical models used are described in this paper. The authors claim that the changes have saved the city over $5 million per year, reduced the fire companies' workload, and established a more equitable distribution of fire companies through the city.

Audience: Everyone.

Issues: A range of deployment issues are addressed.

Policy Utility: This paper presents a useful overview and description of The New York City-Rand Institute deployment work for New York City.

External Validity: The methods used are generally applicable.

**Abstract:** A survey of current research on the allocation of municipal emergency service systems, with the emphasis on police patrol cars and fire engines and ladders. The aspects of allocation policy discussed are (1) determining the number of units (vehicles) needed on duty in each geographical area at different times of the day or week; (2) selecting the unit(s) to respond to a particular incident; (3) determining the locations of patrol areas for the units on duty and designing patrol coverage patterns; and (4) deciding when units should be redeployed to improve service in areas where a large number of units are temporarily busy. The report describes both traditional rules of thumb for allocation and newer quantitative methods based on queuing theory, geographical models, and simulation models.

**Audience:** Researchers, planners.

**Issues:** Survey of methods for allocating emergency vehicles.

**Policy Utility:** A useful discussion of research.


**Abstract:** The authors analyze the distribution of fire alarms in Alexandria, Virginia; analyze fire company availability; and examine alternative fire company locations.

**Audience:** Everyone.

**Issues:** Can operations research be applied to a fire department? How many fire companies are needed and where should they be located?

**Policy Utility:** Low. In part because Alexandria has few fires, there are no real policy implications; data are collected and looked at, and some models are run, but not enough comes out of it.

**Internal Validity:** There are some technical errors.

**Summary:** The paper concerns the application of operations research to the provision of fire department services. "The purpose of the paper is to demonstrate the utility of such an approach to city managers, planners, fire service officials, and other personnel unaccustomed to OR methodology. . . . The paper should be regarded as a practical demonstration that qualitative analysis can be useful to city and fire department decisionmakers."

The paper first describes Alexandria and the fire department. Data were collected on all alarms during May, June, July, and August 1970 and keypunched. For each alarm type, the authors present alarms by time of day and location, the latter by using a grid overly. Given this information, they apply queuing theory and location theory. A queuing model developed by Chaiken (R10:24) is used to determine the probability that sufficient engine companies are not available when an alarm occurs, the probability that there will be a specific delay before enough companies become available, and the fraction of time that companies will be servicing calls. Under location theory, they use two methods to find the optimal engine company locations. The first uses the Maranzana method to minimize average response time city-wide; the second uses a redistricting model that "uses almost the same objective function. In this case, the squares of the response times are used in order to make the districting more compact. However, the model also attempts to balance workload among the various fire stations."

The last part of the paper describes the use of a simulation model to check the distribution of the number of companies busy predicted by the queuing model and to evaluate the suggestions of the two location models.

**Discussion:** The authors frequently present analysis without explaining how it is to be used. For example, they say,

> It is evident that the calls over the 123-day period tend to cluster. This clustering has possible implications for fire station location, assignment and unit relocation policies.

But they don't say what these implications are.

The authors motivate the reader to the importance of queuing theory and "availability analysis" by saying:

> Availability analysis provides a fire chief with such specific information as: "the incidence of a citizen calling for aid when no equipment is available to provide service will (on the average) occur once in four years with seven companies, and once in forty years with eight companies." He may then calculate the costs of providing the two different levels of protection (seven or eight companies) and the average and maximum times callers may expect to wait for an emergency vehicle in each instance. Such data, together with a "per company" cost figure, would inform the citizen as to how much they would have to pay for a specific capability of this vital urban service.

Using the Chaiken model while claiming "the Chaiken model assumes negative exponential service times" (not so), they find in the busiest period the probability that six engines will be busy at the same time is 0.01 or "once in 1,000 eight-hour periods." This last statement is not true.

The authors apparently use the Chaiken model to calculate the probability of waiting more than t times for enough companies to become available for a given alarm. The numbers are suspect since Chaiken does not develop a procedure for getting them.
Since the alarm rate is so low (4 p.m.-midnight = .48 alarms/hour), there is no apparent reason for using the simulation. However, they do so and find that simulation results compare well with the Chaiken model.

The simulation model is used to test a number of station location options. They find that adding a fire station results in an improvement in response time, but is it significant? The answer is no for first and second engine and yes for third engine, so they conclude that the addition of the engine company would improve third engine response time. Why did this peculiar result occur? Clearly, adding a company must improve response time. The reason is probably a combination of two things. First, they minimize average response time to alarms and there are few alarms in the new company's area. Second, they probably didn't run the simulation long enough (although the standard deviation of the individual observations are given, the number of cases is not).

This location analysis reveals that minimizing average response time to alarms is probably not the appropriate objective in Alexandria; it would appear that coverage, which considers response times to different locations but not how many alarms occur at each, is more appropriate, and that some of the options examined would improve it measurably.

R10-5

Abstract: Because data were not available, a major part of the effort was to code and keypunch about 11,000 alarm incidents representing all alarms in a four-month period. The authors identify false alarms and rubbish fires as a problem and focus on imbalances in workload. They recommend elimination of two engine companies; permanent relocation of one engine company; elimination of permanent staffing of fireboat and other special equipment (they suggest manning using nearby fire company members on an on-call basis); more minority recruitment; increased fire prevention effort; investigation of technology such as rapid water, walkie-talkies, and new vehicles; and coordinated effort to eliminate trash fires.

Audience: Researchers, fire professionals.

Issues: False alarms, response boundaries, number and location of fire companies.

Policy Utility: Low because not internally valid.

Internal Validity: The conclusion that two companies can be eliminated, one moved, and response boundaries changed is based upon the goal of equalizing workload. This does not make sense since workload is not a problem. The authors recommend not sending the closest company in areas where the busiest unit responds only about 2000 times.

R10-6

Abstract: In order to obtain quantitative information about the relationship between travel times and travel distances in various regions of New York City, the Fire Department of New York conducted a stopwatch experiment in 1971. Data on over 2,000 responses made by 15 units were collected and analyzed. The report describes the experiment, analyzes the results, and draws conclusions about the travel characteristics of New York's fire companies. A continuous function relating travel time to travel distance is fitted to the experimental data. This function is a square-root relationship for response distances up to some point and linear for longer distances. At their point of intersection, the two functions have the same slope.

Audience: Fire chiefs, researchers.

Issue: How long does it take a fire company to get to the fire scene?

Policy Utility: An important part of predicting what a city's response times would be in different circumstances.

Summary: In order to obtain quantitative information about the relationship between travel times and travel distances in various regions of the city at different times of day, the fire department conducted a stopwatch experiment during the summer of 1971. Data on over 2,000 responses made by 15 units were collected and analyzed.

This report describes the experiment, analyzes the results, and draws a number of conclusions about the travel characteristics of fire companies in New York City. Among the major findings were:

1. In most parts of the city, travel time increases with the square root of distance for short runs and linearly for long runs.

2. Although average response velocities vary somewhat by time of day, the variations are smaller than expected and can be ignored for many planning purposes.

3. There are only small variations in the parameters of the function relating travel time to travel distance in different regions of the city. This implies that the average velocity for a given travel distance is almost constant throughout the city.

As a result, a single continuous function can adequately represent the relationship between travel time and travel distance at all times of day in all parts of the city. This function is a square-root relationship for response distances up to some point and, and linear for response distances greater than d; at the point d, the two functions intersect and have the same slope. When such a function was fitted to the New York City data, the best value of
d was 0.88 miles, and the time/distance relationship was:

\[
T(D) = \begin{cases} 
2.88 \sqrt{D}, & D \leq 0.88 \text{ miles} \\
1.35 + 1.33D, & D > 0.88 \text{ miles}
\end{cases}
\]

where T is the travel time in minutes and D is the travel distance in miles.

R10-7

J. Hausner, Determining the Travel Characteristics of Emergency Service Vehicles, The New York City-Rand Institute, R-1687, April 1975.

Abstract: This report describes the mechanics of a data-gathering experiment and a computer program that can be used to analyze the experimental results. The experiment is designed to gather data to determine the relationship of travel time and travel speed to travel distance and time of day for emergency service vehicles responding to calls for service within a municipality. The resulting empirical travel characteristics are important input parameters for many mathematical models that can be used to study the deployment problems of municipal emergency service systems. The latter part of the report serves as a user's manual for the program and includes a program listing, a description of the input data, a detailed explanation of the output, and a sample printout.

Audience: Fire department researchers and planners.

Issue: What is the relationship between fire vehicle travel time and travel distance?

Policy Utility: High.

External Validity: The methods presented can be used in all cities.

Summary: Travel time, defined as the time from the dispatch of an emergency unit until its arrival at the scene of an incident, is an important measure of the performance of an emergency service. However, most municipalities know very little about how quickly their emergency units respond and how travel times and travel speeds vary with response distance, time of day, and region of the city.

This report discusses a procedure for determining the travel characteristics of emergency service vehicles. It involves (1) conducting an experiment to collect data on a large number of responses and (2) analyzing the resulting data using a computer program that has been given the name "Travel Time Analysis Program." Instructions and data collection forms are provided for conducting the experiment, and the computer program is described, including the input data and output reports.

The program summarizes the experimental data and estimates the relationship between travel time and travel distance by fitting several curves to the data. The effects of the time of day and weather and traffic conditions on travel speed are also examined.

R10-8


Abstract: Volume I (not reviewed in this report) describes computer applications in the Wichita Falls Fire Department, including a new data collection and reporting system and a computer-based fire inspection system. Volume II begins with an analysis of alarm incidence and then describes a computer simulation model. Volume III contains a discussion of alarm incidence, development of hazard indices for each area of the city, application of the simulation model to a number of deployment issues, a brief section on long-range planning, and a discussion of the insurance grading system used in Texas.

Audience: Everyone.

Issues: Fire incidence analysis; developing a computer simulation; the number of men on duty by time of day; the number of fire companies needed and their location; and fire insurance.

Policy Utility: The alarm incidence analysis and simulation model are potentially useful. However, a principal recommendation based on the incidence analysis—varying the number of men on duty by time of day—is inappropriate for Wichita Falls. The simulation was improperly used to evaluate this policy and was not needed to evaluate the other deployment policies described.

Internal Validity: Ranges from good to poor.

External Validity: The simulation and incidence analysis could be applied in other cities but the deployment analysis should not be.

Summary: Incidence Analysis. Data representing all the 9,450 incidents that occurred in Wichita Falls, Texas from 1964 to 1968 were placed on magnetic tape. The codes were aggregated from the uniform national fire codes, and each incident was assigned one of the classes: grass, structure, auto, trash, false, and other. The number of incidents of each type are tabulated or graphed by hour of day, day of week, week of year. There is much variation over a day and over the year but little difference by day of week. Grass fires respond dramatically to average rainfall. Histograms of damage estimates, injuries, fire cause, method of extinguishment, and "how reported" are presented. In addition, damage level is examined by hour of day. Fires with reported damage levels exhibit two broad peaks, one from noon until 6 p.m. and a second from 9 p.m. until 4 a.m. In contrast,
all alarms exhibit a single, very pronounced peak from noon until 6 p.m. The geographic distribution of alarms is presented on maps of the city.

This analysis provides most of the input data required by the simulation. This portion of the work also resulted in two recommendations: (1) Since total alarm rate is much lower between 10 p.m. and 8 a.m., the number of men on this shift should be lower; (2) since average utilization of fire personnel in fire suppression activities is very low, they should perform additional service, such as more preventive inspections.

**Simulation Model.** The computer simulation model, written in FORTRAN IV, is divided into three phases: initialization, simulation, and analysis. The documentation of the program is not complete but should be adequate for making a decision about whether to use this model.

The initialization phase reads in the description of the resources to be simulated and probability descriptions of the incidents to be simulated. Alarms are generated by assuming each type of alarm (at most four types are allowed) is an independent Poisson process. In conformity with the results of the incident analysis the mean alarm rate is assumed to vary by time of day and week of the year but not day of week. In general, one would prepare an array giving mean alarm rates covering the entire year. The total alarm rate, distribution of alarms by type, and the season to be simulated could then be easily changed from run to run. The city is divided into geographic "fire zones," and the distribution of alarms over these zones varies by type of fire.

Following the initialization phase, control is turned over to the simulation phase. When an alarm is received, the "response strategy section" of the program is called to decide on the initial dispatch. Details of the present implementation of the response strategy are not presented, but since it is a separate subroutine it could be changed. Travel time may be input in terms of a complete fire station—fire zone matrix or calculated. If calculated, right-angle distances and an empirical distance versus time function are used. The duration of the incident depends only on type of incident. Companies are not available until they return to their fire stations. That is, they cannot be dispatched while en route to their home stations. (At low alarm rates, this is not a problem.) Second alarm fires cannot be simulated. The initial response is assumed to be adequate, but not always necessary, and the unused equipment returns immediately to the fire station.

The input includes the number of men assigned to each fire vehicle and the average number of men at the scene of incidents. However, the number of men on the scene does not affect the duration of the incident.

The simulation phase writes a complete record of all the activity at each fire. This record is processed by the analysis phase, which is a separate program. Therefore, analysis of any run may easily be performed. The current analysis program provides data on only utilization of resources and average and maximum first response time.

**Deployment Analysis.** The simulation was used to test several deployment policies:

1. The locations of two booster trucks were changed but resulted in no improvement in response time. Keeping the current locations but adding a third booster truck (not surprisingly) resulted in an improvement in response time.

2. Future land use predictions were derived from a planning document and related to hypothesized increases in alarm rate and changes in distribution by type and location. The performance of the present resources was simulated in the changed environment and found to be adequate, with the possible exception of the booster trucks.

3. A series of runs attempted to show the effect of reducing the number of men assigned to the night shift and redeploying them during the day in two-man companies roving in a car with a portable fire extinguisher. The outcome is discussed below.

**Fire Hazard and Fire Protection Evaluation.** An attempt was made to assign indices that would represent the level of fire hazard and of fire protection in each zone of the city. Separate fire hazard indices were assigned for each of four types of fires: structure, grass, auto, and other. The factors that contribute to fire hazard (population density, building construction, etc.) and fire protection (inspections, distance to first due pumper, water availability, etc.) were enumerated and a scale produced for each factor. A fireman assigned ratings to each factor, and the factors were aggregated to produce the required indices. An arbitrary threshold was picked for all the suggested indices, and any index below the threshold was deemed undesirable. (For one of the indices, this meant 75 percent of fire zones were unsatisfactory.) Plots of indices were produced.

**Fire Insurance Grading in Texas.** Comments are made on the "Key Rate" system used in establishing fire insurance ratings for Texas cities. The rating is developed for the city as a whole. This is seen as being unfair since the quality of fire protection and fire hazard can vary greatly within a single city.

It is shown that alarm boxes are not an important source of fire alarms in Wichita Falls (52 fires were reported in this manner in 1970) and that they cost $24,000 per year. It is therefore recommended that the rating system should place less emphasis on alarm systems.

It is recommended that the rating system place more emphasis on fire prevention activities of the fire department.

**Discussion:** Incidence Analysis. The location and timing of fires are important in planning resource allocation. The method of presentation used in this report may be of interest to those considering a similar study of the incidence patterns of a different city. The report also provides a useful case study of one way to develop the input data required for a simulation of fire department
operations. The data are presented in a readable, useful format. The authors relied almost exclusively on tabulations and consequently did not consider many interactions. However this does not cause any problems.

The recommendation to make the number of men on the night shift lower than during the day cannot be justified in a city with an incidence pattern and resources like those of Wichita Falls, which has fewer than 2000 alarms per year. Average utilization is very low; each pumper company works at an average of less than one incident per 24-hour day. Consequently, alarm rate is much less important in determining the number of companies (or men) that should be on duty than the need to provide minimum standards of coverage. Since serious fires (as measured by those with damage greater than $500, for example) occur as frequently between midnight and 1 a.m. as any other time, the standard of coverage at night should be at least as high as during the day.

**Simulation Mode.** Some cities might find this model more useful than either the Rand or NBS simulation models because FORTRAN is more widely available than SIMSCRIPT. Following (probably minor) programming modifications (primarily response strategy and additional analyses) the simulation could be used to study the effect of fire station location, vehicle assignment, alarm rate, and alarm distribution on response time and resource utilization. Because there is no provision for simulating a historical stream of alarms, the cost of preparing the input may be slightly higher than for other models. However, the analysis required for data preparation may itself be useful.

The model is quite simple and has high face validity for the applications mentioned above. Statistical tests show no difference between alarm streams generated by the model and historical data. Incidentally, the empirical data comparing response velocity and response distance exhibit a period of acceleration to cruising velocity and no time of day effect, exactly as has been found elsewhere.

**Deployment Analysis.** Applications (1) and (2) described above demonstrate the limited range of insight that can be derived from a dynamic simulation of an essentially static situation. The alarm rate in Wichita Falls is so low that a much simpler static analysis would have reached the same conclusions. Application (3), the evaluation of manning levels, would require a simulation, but this one is not appropriate, as is discussed below.

The analysis of the simulation results is naive. The sole bow to statistical reliability is that the base case of 700 alarms was replicated once. Since the results were in close agreement, it was then assumed that the probabilistic variation was not so severe as to distort evaluation of strategies. From there on, each number is treated as an absolute. However, since no important differences showed up, the lack of analysis is not too important.

There is a serious problem with the validity of the runs that attempt to evaluate the roving companies. The reduction in personnel on the night shift was done by a reduction in firemen per vehicle with no reduction in the number of vehicles simulated. Since the number of men per vehicle does not affect the course of simulated fires in any way, there was of course, no degradation in performance during the night. The only change in the output was a reduction in the number of men on the scene, but since only average values of this variable were examined, and more men were dispatched per incident during the day, the variable actually increased. Also, since the response time criterion was delay to first arrival, with six additional locations (base case had seven), this naturally improved. No consideration was given to the difference between the arrival of a fully equipped engine company and the arrival of two men and a fire extinguisher. The model cannot address this difference, but this is the crucial difference in examining manning levels.

**Fire Hazard and Fire Protection Evaluation.** If such indices could actually be estimated in a rational manner, they would provide a means of evaluating current and alternative resource allocations and of pinpointing zones with less than acceptable fire protection. However, no explanation is given as to how the scales were developed for each factor or what weights were used to combine factors. Filling out the rating forms requires much subjective judgment on the part of the firemen. No attempt was made to find out how reliable the ratings were—i.e., the size of the variation when different firemen evaluated the same zone.

R10-9

**Abstract:** A computer model of the response of the fire department, written in SIMSCRIPT, is completely documented in this report. The model simulates a string of alarms that are described on the exogenous event tape and usually have been derived from a historical record. When an incident occurs, one or more demands for service, called ALARMS, are scheduled. At each ALARM an assignment subroutine finds the closest available companies and dispatches them. To change the assignment algorithm would require only changing one subroutine. Travel times are calculated using the right-angle metric and assuming a constant velocity (which may vary between emergency and nonemergency runs). The duration of the time to be spent on the scene is specified on the exogenous event tape, and after completion of this period the company travels home.

**Audience:** Programmers, systems analysts who would use or modify the model. (The paper assumes some knowledge of SIMSCRIPT.)
Issues: The model could be used to evaluate the number and locations of fire companies.

Policy Utility: Low in its present form.

Internal Validity: Adequate, but does not provide output data needed to make statistical comparisons of policies.

Discussion: The program allows only two kinds of companies (engines and ladders) to be simulated. The paper states that the model is "best suited to model fire departments in relatively small cities," presumably because the model has no provision for simulating relocations or "move ups," and the computer time required increases dramatically with the number of companies being simulated. The latter requirement appears to be because the assignment routine performs a complete ranking of all available companies in order of response time. A minor programming change to find just the closest companies could ameliorate that problem.

The only policy variables that can be addressed with the current version of the program are the number and location of fire companies. However, by rewriting the assignment algorithm one could examine initial dispatch policies.

The costs associated with implementing the model in a particular city will be quite high. The incident data for the city would have to be processed to produce the exogenous event tape. The program should be modified to improve the output so that statistical tests could be performed. And, of course, the running time of the simulation is large.

It is difficult to justify the expense of using any simulation for an analysis of fire company locations, although a case can be made that simulation to examine initial dispatch policies for which models are not available would require extensive rewriting. But in this it is not much different from other available simulation programs.

The model relies entirely on its face validity, which is quite high since it uses historical data for the exogenous event tape, contains very few assumptions (the dispatcher always knows which companies are closest, right angle distances, constant velocity), and is extremely simple.

The report does not describe the results of any study of policy alternatives. The simulation model is quite similar both in general structure and in detail to the Rand simulation model, although it does not contain the same degree of flexibility. The lack of flexibility carries with it a reduction in the amount of input data that must be prepared.

The main advantage of the NBS simulator is that it accumulates statistics by shift and by day of week. The usefulness of this feature is somewhat limited because there is currently no provision for varying the number of companies on duty by shift or for analyzing the effects of time, varying alarm rates.

The major deficiency of the NBS simulation is in the output. Not a single standard deviation is contained anywhere in the output and there is no means of making statistical tests for differences between policies. The measure of coverage is the number of idle resources per shift, which is sampled once an hour. Also, the user cannot vary the amount or kind of output produced by the program.

R10-10

Abstract: This paper is a nontechnical overview of the NBS simulation of fire department operations (R-1188/2), designed to help administrators and officials understand when the simulation should be used, how it works, what information it supplies, and what data and resources are needed to use it. The program is large, complicated, and expensive to operate, requiring a lot of detailed input data and the services of experienced analysts. Therefore, a description is given of the circumstances in which models simpler than the simulation would be more appropriate. The simulation program tracks each of many incidents from the time the fire is reported through the dispatching of fire-fighters, their arrival and callback, work, release, return recovery, and availability for another dispatch. Its purpose is for analysis of proposed new deployment policies. Results are reported in terms of response times, coverage, and the activities of fire-fighting units. Sources of further information are listed.

Audience: Everyone.

Issue: The development and use of computer simulation.

Policy Utility: An essential introduction to anyone thinking of using simulation.

R10-11

Abstract: This paper describes a simulation program that can be used to compare allocation and dispatching policies. The package consists of an incident generator that produces a description of the incidents to be simulated, the simulation program itself, and the postsimulation analysis programs that provide analysis of the output.

Audience: Programmers and researchers.

Issue: The development of a computer simulation model.
Policy Utility: Useful for large cities.

Summary: The simulation described in this report was written to study the dispatching and deployment operations of the Fire Department of New York. The structure of the program is sufficiently general that, after only minor modifications, it could be used to study the operations of any large metropolitan fire department.

The simulation model is designed to examine the effect of modifications of either the number of companies on duty, the location of fire stations, or the rules used to dispatch and deploy the available companies. Alternative policies may be compared with respect to delays from the moment an alarm is turned in until each firefighting unit arrives at the scene of the incident, the workload on individual firefighting units, and the coverage being provided at periodic intervals.

The simulation program is divided into three phases, each of which is a self-contained program:

(1) An incident generator produces a description of the incidents to be simulated.

(2) The simulation program simulates the response of the fire department to the set of incidents for a particular allocation policy. Usually this program is run a number of times using different policies but the same input file.

(3) The postsimulation analysis programs provide further analysis of the files produced by the simulation runs. The report describes only one such program; it produces statistics on the differences of the response time vectors of two simulation runs that used the same stream of incidents. (The others have been special-purpose programs, written for particular applications.)

The incident generator and the simulation are written primarily in SIMSCRIPT II.5. The postsimulation package and three of the simulation subroutines are written in FORTRAN.

The paper describes each of these programs and their data requirements in sufficient detail that a user who is familiar with SIMSCRIPT should be able to run or modify the program. Flowcharts, complete program listings, sample data decks, and program outputs are included.

R10-12

Abstract: This paper describes a simulation model developed as a tool to aid deployment decisionmaking for the New York City Fire Department. The model, written in SIMSCRIPT II.5, has been used to evaluate alternate solutions to workload and response problems plaguing the city. These solutions involve new policies for locating, relocating, and dispatching firefighting units to utilize resources more effectively. Several specific applications of the simulation are described. In addition, methodological issues concerning the design and use of the model are addressed.

Audience: Fire chiefs, planners, researchers.

Issues: A range of deployment issues are discussed.

Policy Utility: High for large cities, lower for other cities.

External Validity: The methods are generally applicable, although the solutions usually apply only in the largest cities.

R10-13

Abstract: A simulation model designed to compare different policies for locating, relocating, and dispatching firefighting units is described. Issues treated include: the use of internal measures of performance as proxies for global ones; the use of analytical models for various subproblems to yield policies to be tested; the handling of loss of life and other important but rare events. The SIMSCRIPT II.5 simulator and input and postsimulation analysis programs are described. Results that have been used by the Fire Department of the City of New York are presented and analyzed.

Audience: Fire chiefs, researchers.

Issue: The development and use of a simulation model.

Policy Utility: The applications devised here are mainly of use to large cities.

Summary: This paper describes a simulation model designed to compare different policies for locating, relocating, and dispatching firefighting units. Simulation experiments were made to compare proposed solutions to workload and response problems with the then current policy in New York City. The proposed policies involved creating new units, some of them to work only in peak alarm rate hours (Tactical Control Units), and reducing the number of firefighting units dispatched to street: box alarms during those hours (Adaptive Response). The paper reports a simulation experiment in which one new policy reduced both the total number of responses made by all engines and the average time from first report of the fire to the arrival of the scene of the first engine and, if needed, a second and a third engine. This and other simulation experiments are credited with assisting in the adoption and implementation of TCU and AR in New York City in late 1969.

Several issues concerning the design and use of the simulation model are described. The first of these is the use of internal measures of performance, such as average time from first report to arrival of an engine, in place of global measures, such as loss of life. The second is the
integrating of insights gained from analytical models of the various subproblems (initial dispatch, relocation, etc.) into policies to be tested by simulation. The third is the use of "virtual" measures, a Monte Carlo-like technique for efficient handling of loss of life and other important but rare events.

Aspects of the operations of the Fire Department of the City of New York and their translation into SIMSCRIPT I.5 program are described. In addition, programs that provide input to that simulator and analysis of simulation output are described. Statistical analysis is made of the reliability of the differences in time required for arrival of the third engine under a proposed policy and the current one.

R10-14

Abstract: This paper describes an analysis of the need for fire companies in New York City. It consists of four areas of study: (1) the linear distribution of fire companies; (2) burnable material; (3) company work performance; and (4) mass response problems. The results of the study were recommendations for the elimination and relocation of fire companies.

Audience: Everyone.

Issue: How many fire companies are needed and where should they be located?

Policy Utility: Low. The study is of interest historically. However, in general, the analysis reported bears little relation to the final recommendations.

Internal Validity: The work gives the impression that a good deal of relevant analysis was done. Close examination indicates that this was not the case. Evidently, the recommendations were based mainly on subjective judgment; the solution does not follow from the analysis.

External Validity: The Valinsky approach is essentially a consideration of hazards. It is most similar to the ISC approach.

Summary: The study reported here was performed by Valinsky and A. C. Hutson, a fire protection engineer. Hudson wrote a separate report, "Number and Distribution of Engine and Ladder Companies in the City of New York," which is not reviewed here, although the two reports are meant to complement each other.

The original Valinsky paper (almost all of it is contained in the Operations Research version) is divided into three parts. Part I describes the highlights of the analysis and gives the results; Part II contains the technical and statistical methods used; Part III presents recommendations for improvements in the fire reporting system.

The analysis consisted of four major steps:

1. An Analysis of Linear Distribution. Comparisons were made between actual response distances in New York City and National Board of Fire Underwriters standards. A map was constructed (but not shown) with an initial company distribution exceeding the requirements of the standards.

2. An Analysis of Burnable Material. More than 36,000 blocks in New York City were examined and their characteristics plotted on maps. As a result of this analysis, more companies were added to provide coverage in areas of high hazard.

3. An Analysis of Company Work Performance. The purpose of this analysis was to determine the expected availability of the companies tentatively placed by the first two steps. For each company, using a five-year period, a number of workload-related measures were calculated: average number of responses per year; average number of workers per year (incidents that require the services of the company); total work time; and average time out of quarters.

Using all of the alarms that occurred in one year in March, June, September, and December, the distribution of fire incidence by time of day and borough was determined. In general, fires were found to peak at about 5 p.m. As a result of this analysis, more companies were added in regions where workload was high or tended to be increasing.

4. An Analysis of Mass Response Problems. The final phase of the study was an analysis of the potential for serious fire situations. Four factors were considered: distribution of greater alarms; fire seriousness, as measured by property loss and damage; the distribution of fire fatalities; and probabilities of extreme fire situations. Using this analysis, "adequate provision was made to meet the probabilities by the last additions made to the plan of company distribution."

To test the recommended plan, the Fire Department provided descriptions of the three most serious fire situations that had arisen during a ten-year period. Assuming that the recommended number of companies had been in operation, the number of available companies at the one point in time was determined for each of the situations.

Discussion: The major shortcoming of this study is that the results are not clearly connected to the analysis. Time after time, claims are made that a certain part of the analysis was used to arrive at the conclusions but, in most cases, no evidence is given to support this contention. In any way is the result a "statistical determination" of the need for fire companies as the title states; instead, it is based mainly on a subjective evaluation of hazards.

On p. 497 of the Operations Research paper, it is stated, "the four phases of study outlines summarize the approach to the problem. In order to explore each to its limits, however, many separate factors required de-
tained study." A list of 16 factors is given, including size of area to be protected, vertical problems of structures, sprinkler and fire-detection protection, population density, company staffing, modernization of fire-fighting equipment, and budgetary constraints. "Detailed analysis of each of the foregoing factors, as finally presented to the Mayor's Committee, actually required several manuscript volumes." For the exemplary purposes of the present paper, it is proposed to examine only a few of them that may be characterized as of major importance to the overall problem. The original and longer paper contains the exact list of factors with no reporting of the "detailed study" that was undertaken and no sign of the "several manuscript volumes." In fact, the shorter Operations Research paper contains all of the relevant information from the original report.

The impression is given in both papers that the statistical analysis of fire incidence by area was used in the analysis of burnable property. On p. 409 of the Operations Research paper, it is stated, "In the following paragraphs, the Borough of Manhattan is used as an illustration of how these methods were applied." From the longer paper, we see that the analysis was done for only parts of Manhattan and was "primarily exploratory."

Similarly, it is not clear how the analysis of company workload and the time-of-day pattern of alarms is used. For example, what use is made of the result that the lowest 10 percent of the city's engine companies averaged nine responses per month in 1946-50 while the highest 10 percent averaged 50. After presenting fire incidence by time of day and borough, the author states, "Naturally, day-by-day variations were found and all extreme days were noted and given special consideration as planning proceeded" (p. 509, Operations Research paper). But what special consideration was given? The author does not say. It is stated that fires peak at about 5 p.m. and that this information and the related increase in traffic at that time were used to develop the plan. Again, how was it used?

There are many other instances, particularly in the longer paper, where statements are made that analysis was done, or that factors were considered, with no documentation of the analysis. Frequently, the problem addressed is a very difficult and complex one, such as the analysis of the geographic distribution of fire fatalities.

R10-15


Abstract: A procedure is developed for determining the best locations for fire stations. In paper (1) the objective is to minimize the sum of fire losses and fire department costs.

Audience: Everyone.

Issues: Number of stations needed and their sites.

Policy Utility: Potentially high. Knowledge about how allocation decisions affect fire damage is central to intelligent policymaking. Paper (2), because it uses relationships between damage and response time, should be of interest to everyone, from policymakers who would use the relationship to researchers concerned with its precise specification.

Internal Validity: Generally excellent, although there is some question about the validity of the relationship between monetary loss and attendance time.

External Validity: It is not known whether this relationship, if valid, applies outside of Britain.

Summary: In general, the optimal number of fire stations is achieved when the cost of adding one more station exceeds the value of fire losses averted (including loss of life). This principle is applied in paper (2), while in the otherwise similar paper (1) the relationship between response time and fire loss had not yet been estimated, and therefore the objective was to minimize the total travel time for all fire units needed at all incidents.

The approach has the following characteristics:

(1) The city is divided into small homogeneous sub-areas. The rate of fire incidence is assumed known, or can be estimated from population densities, following earlier work of the author.

(2) Should a station be located in one of the subareas, it is assumed to be at a major street intersection near the center.

(3) A matrix of travel times between subareas is determined from run data, experimental trips of fire apparatus, or use of a speed-calibrated road network together with the judgment of experienced fire officers as to the route that would be followed. Speed of travel was found to vary by time of day, and incidents were categorized accordingly.

(4) Turnout time is added to travel time (of particular interest because the possibility of having "retained" companies was to be explored; these are companies that are manned when needed by drawing on a pool of part-time employees).

(5) As necessitated by available data, fire losses as a function of response time were assumed not to depend on the subarea in which the fire occurred. The functional relationship, determined by the author, is reviewed elsewhere.

The minimization method is an algorithm written by the author. This appears to begin with the assumption that all potential sites are filled; then it determines which site, if eliminated, would cause the least increase in the objective function. On the next iteration, the previously rejected site must be considered for inclusion after the best site to eliminate has been found. This
process continues until there is only one site, yielding the best choice of r sites out of n for all r less than n. No claim is made that the program actually finds the optimum, but there is an implicit assumption that it does.

The minimum cost solution is found by comparing the total costs for the optimal siting of r companies over different values of r. The result depends on whether nonbuilding fire losses are included. When retained companies are considered, the total cost curve has a wide, shallow minimum, and therefore a range of solutions become equally acceptable, given uncertainties in the data.

Discussion: Conceptually, this work is among the best in the field. However, minimizing total travel time can result in poor coverage in some areas. The strong point of this work is its attempt, in paper (2), to associate total costs with alternative siting and manning decisions. Particularly noteworthy is the way it relates attendance time to those decisions and then calculates fire loss from attendance time.

In the author's relationship, the average direct fire loss (figuring an English pound is $2.40) in a dwelling is about $1700 if attendance time is one minute and about $5200 if it is 20 minutes. The increase in average loss goes up as attendance time increases; for example, the average loss at two minutes is $142 more than the average loss at one minute, while the average loss at 20 minutes is $247 more than the average loss at 19 minutes. For fires in other occupancies, the average loss is larger and grows faster: It is about $5200 when attendance time is one minute and $44,000 when it is 20 minutes.

This relationship between time and monetary loss is based on other work by the author. However, the published version of that work relates attendance time and a physical measure of damage—whether the fire was confined to the room or floor of origin. It was done using fires from the entire United Kingdom. The damage-to-dollar-loss conversion was "derived from studies of the 1966 losses in Glasgow."

Total fire losses are assumed to be 80 percent more than direct losses in structural fires. This estimate is based on outdoor fire losses being 25 percent of direct structural loss in the United Kingdom in 1963 and on a study indicating that "consequential" losses (from lost business, employment, etc.) are about 30 percent of direct losses.

The difference between "retained" and "whole time" manning is roughly equivalent to the difference between volunteer and paid departments in the United States. In Hogg's analysis, the turnover time for retained units is larger than for whole time companies. A fixed amount of money spent on fire protection would buy more retained companies than whole time ones. The retained companies have longer turnover times and, since there are more of them, shorter travel times. The issue then is which manning policy, or, more precisely, what mix of whole time and retained manning, does better on attendance times and then total fire loss? Does the answer for Peterborough apply elsewhere?

How physical damage was converted to dollar loss is not revealed. Is the conversion valid? A number of questions are unanswered:

- The conversion was based on damage and loss in Glasgow in 1966. Does this apply in other cities at other times?
- Does the relationship between losses from outdoor fires and structural fires for the United Kingdom in 1963 apply in particular cities at other times?
- Is the relationship between "consequential" losses (lost business and employment, etc.) and direct fire losses valid? If so, where and when?
- Is the relationship between attendance time and damage, developed using all fires in the United Kingdom in 1963 and some in 1963, valid?
- Does it apply in particular cities at other times?

R10-16

Abstract: When the study began, East Lansing had two fire stations, one near Michigan State University (MSU) and fairly new, the other downtown and old. The downtown station had to be replaced. In addition, "plans," based upon insurance standards, were being made to build two more stations to meet future growth. A computer model was used to evaluate alternative locations. It was assumed that the MSU station would remain. An evaluation was made of three additional stations. For each number of stations, response boundaries were determined. For each response area, the best location is chosen by minimizing weighted response time. Each building is given a numerical weight based upon population, height, construction type, and area. For each factor, points are assigned as a function of the value of the factor (e.g., height: 1 and 2 stories = 0 points; 3 and 4 stories = 2 points; 5 and 6 stories = 4 points; 7 and over = 10 points). The points are then added together and multiplied by 1 for all occupancy types except schools and churches where they are multiplied by 1/3. As a result of the study it was concluded that the alternative of retaining the MSU station, relocating the older station, and adding just one station offered the best combination of benefits and costs.

Audience: Everyone.

Issues: How many fire companies are needed and where should they be placed?

Policy Utility: Low because of questionable methodology.
Internal Validity: Questionable.

Discussion: Both papers may give the appearance that some useful analysis was done, but the appearance is deceptive. The process of assigning weights to buildings makes little sense since the numerical values are purely subjective. On p. 6 of the NBS report it is stated, "The 'weighting function' was devised by systematically correlating structural and demographic characteristics of all land use types with the statistical results of an analysis of the city's fire history data." However, no data are given in the report showing the analysis. The claim is made that actual fire incidence relates well to the weights, but the weights are supposed to represent hazards, not incidence. The authors say that using posted speeds is a good approximation and that computer-calculated response times compare well with actual response time, but they give no data.

The ICMA paper states (p. 15),

An attempt was also made to change district boundaries by reassigning some demand sites to other districts. Factors influencing this reassignment were work loads of associated fire companies and expected demands. After such redistricting the model was run again to see if a new, possibly more efficient, solution could be obtained. Analyses were also made with variations in future development (annexation possibilities) and with variations in penalty score weighting factors.

Figure 3 in the NBS report shows the new boundaries, and one boundary looks as though it is not the "closest unit" boundary. However, such a solution does not make sense because of the low alarm rates in East Lansing.

None of the results of the computer runs are given—not one number or example. Possibly the city officials decided they needed three stations and knew where they wanted to put them. The role of analysis in this decision is unsubstantiated.

It should be noted that this study is part of the historical development of the Public Technology, Inc. fire location procedures R10-17.

R10-17


Abstract: These papers are all directed at the question of fire station location. The city is divided into fire demand zones and a computerized street network is developed. Estimates can then be made of fire company travel times between potential station sites and demand zones. For each demand zone a target travel time is specified based on subjective estimates of hazard. The general goal of the method is to find the configuration of stations that comes closest to meeting the targeted travel times.

Audience: Local government officials and top administrators of fire departments (4; Parts (a), (b)), fire department planning officers (4; Parts (c), (d)), operations researchers (1, 2, 3).

Issues: Number of stations needed and their sites.

Policy Utility: Potentially high, because package is readily available and immediately usable.

Internal Validity: Several problems have been raised regarding algorithms used and performance measures considered. None of these is inapplicable in applications. More troublesome, however, is that the documentation does not give any examples (real or hypothetical) of how alternative site configurations are compared.

External Validity: The approach is generally applicable.

Summary: The street map of the city is converted into a computer-readable network description, in which intersections are represented by nodes, and streets are represented by connecting arcs among nodes. It is not necessary to include all streets in the network; main arteries together with a sufficient number of other streets will be adequate. The travel speeds of responding fire companies on the arcs must be estimated in any one of several ways: by using experienced guesses of fire officers who have operated in the area, from data collected in traffic surveys, or by conducting an experiment in which the travel times of fire companies along arcs are recorded.

By means of a shortest-path algorithm, it is possible to determine, for any two nodes, the route that has the lowest possible travel time. This is assumed, for purposes of analysis, to be the actual travel time.

Some of the nodes are identified as "focal points." Each focal point is located approximately at the center of a "fire demand zone," which is a subarea of the city having fairly homogeneous fire protection requirements. The size of a fire demand zone is such that the

1 This methodology was developed and applied by Public Technology, Inc. (PTI). The four papers under review do not completely describe the methodology; in particular, the interrelationships among the four papers have not been completely explained therein. Secondary sources such as briefing materials and private communications have also been relied on for this review.
time to travel across it is not considered critical for fire suppression purposes, ordinarily less than 30 seconds. However, a demand zone can be as small as a single complex of buildings. All potential fire incident locations within the demand zone are treated as if they were located at the corresponding focal point.

The potential locations for fire stations are also identified with certain nodes in the street network. These would ordinarily include existing station sites as well as others selected on the basis of land availability and accessibility to the streets and highways.

In the early versions of this work, a measure of the importance of responding to each focal point had to be determined. For example, in paper (1), this measure consisted of calculating a "weight" for each structure in the demand zone and adding the weights for all the structures. The weight captured information about the use to which the structure was put (occupancy type), the population in the structure, its height, age, and area, and its type of construction. The functional form of the "weight" was determined through regression analysis of previous fire records in East Lansing, Michigan, using fire loss as the dependent variable and the variables just mentioned, together with travel time, as the independent variables.

In papers (2) and (3), the importance of a focal point would be established by specifying the maximum first due travel time of a fire company that would be permitted to the focal point. This constraint on the travel time to the focal point is supposed to be determined in a subjective fashion by the fire department concerned. One justification given for this formulation is that any fire has a flashover point, after which it will be substantially more difficult to extinguish, so an objective of the fire department should be to arrive prior to flashover.

Assuming that constraints on travel time have been established, the next step in the methodology is to consider the fire station location problem as a matter of "covering" all the focal points using the fewest possible fire stations. This means that a minimal set of station locations is to be found so that the first due travel time to each focal point is within its desired constraint, with the time calculated according to the shortest path along the network. Here, "minimal" means that no subset of the potential station locations having fewer stations would meet all the constraints.

In principle, techniques of integer programming apply directly to the covering problem, although there may not be any solution, and, if there is a solution, it need not be unique. In practice, because of the potentially large number of focal points and the need to keep costs of computer time within reasonable bounds, approximate solution algorithms have been developed. Paper (2) describes an algorithm in which a linear program is used to minimize $\sum x_i$, subject to the constraints, where $x_i = 0$ if no station is to be located at the jth potential site and $x_i = 1$ otherwise. If the solution involves integer values of all the $x_i$, the problem is solved. Otherwise, an additional constraint on $\Sigma x_i$ is introduced and the linear program is operated again.

In paper (3), an even faster algorithm is developed. This rests on row and column reduction of the constraint matrix. If complete reduction occurs, a solution is found. Otherwise, the resulting matrix is "cyclic," if this matrix is small enough, the method of paper (2) is used, or "brute force enumeration" of possible solutions is tried. If the cyclic matrix is too large, the algorithm stops, having failed to find a solution.

Various technical tricks can be used to see additional feasible solutions, above and beyond the one given in the first run of the computer program. The values of the constraints can be changed slightly, or the program can be further constrained to include a specified set of potential station locations (this is called "seeding").

The computer program produces descriptive output on the configuration of station locations thus generated, such as expected travel times, an analysis of the focal points that receive a first due travel time greater than the specified maximum (called "uncovered" focal points), and other characteristics of the configuration. In the most recent documentation (paper 4) the evaluation procedure itself (obtained by seeding all the sites in the configuration to be evaluated and deleting all others) is called a "Type I" run, and use of the optimization procedure is called a "Type II" run. Without performing any Type II runs, it is possible to consider various alternative configurations of stations by evaluating them with the output from Type I runs. This information would then be combined with operating and facility costs in a subjective manner to select the final station configuration desired, or to develop new alternative configurations for evaluations.

The PTI documentation (4) provides the user with extensive step-by-step instructions and data forms to help in designing the road network and performing analysis using Type I runs.

Discussion: The primary conceptual difficulty with the optimization methodology (Type II runs) is the requirement to establish a constraint on the maximum travel time of first due units to each focal point. First, there are no recognized standards for establishing such constraints. Second, the justification for the approach in terms of flashover fails to be useful because of the lack, at this time, of a quantitative relationship between time to flashover and building characteristics, and also because of doubt as to whether the first arriving unit would necessarily be capable of preventing flashover. Third, the total time from ignition to the beginning of extinguishment includes a reporting delay, dispatch time, turnout time, and setup time as well as the travel time. But travel time is the only variable considered in establishing a constraint. Although the travel time alone may be an appropriate measure for comparing alternative station configurations, under the assumption that the other delays are independent of the configuration, it is not appropriate when a numerical constraint on the
response time\(^2\) needed to prevent flashover is being set. Finally, the process of selecting the constraints will naturally include considerations of life hazard, proximity of other buildings (exposures), and other matters unrelated to flashover, but guidelines for doing this have not been rigorously established.

Aside from these conceptual difficulties, there is the practical problem that, once the constraints are established, the number of station locations needed to meet the constraints may far exceed any reasonably foreseeable budget for the fire department. To proceed with the analysis, it is then necessary to modify the constraints so as to bring the proposed station configuration in line with feasibility. This is accomplished by means of a sliding parameter that we will call \(s\). All travel time constraints are expressed as a plus or minus something: at the start, the value of the parameter \(s\) that corresponds approximately to the available resources of the department is not known (although reasonable rules of thumb for this could easily be developed). The program is set up so that a maximum and minimum value of \(s\) can be specified, and an increment by which \(s\) will be varied. The program will repeat its calculations, stepping \(s\) down from its maximum to minimum value. This trial-and-error method appears to be a defect of the methodology, but in some cities this process has proved to be a useful educational experience for fire officials.

Experience with the PTI computer program that determines the minimal number of station locations needed to meet all the constraints (Type II run) has shown that the algorithm may actually fail to operate in practice (see Hendrick, Plane, et al., 1975). In this case, the program indicates by an error message that the constraint matrix is cyclic. For this reason, PTI advises users (paper 4) that the Type II mode of operation "is developmental, and requires direct involvement by PTI representatives." They further warn that Type II runs are "not usually recommended as a routine procedure since the results are not reproducible without extensive interaction from trained personnel."

When a Type II run actually produces a solution, it is only one of a potentially large number of solutions having the same total number of station locations. These other solutions, which are unknown, may be preferable in regard to the number of existing stations that would have to be abandoned to achieve the indicated configuration, the actually achieved maximum travel time to a focal point, and average travel time.

It is possible to identify some of these alternative solutions by seeding some existing stations and determining whether the resulting solution still contains the minimal number of stations that has been identified from the unseeded solution. In regard to average or maximum travel time, the algorithm does not consider these measures in any way. It is therefore possible to obtain such conceptually unsatisfactory outcomes as the following: The constraints may be contracted slightly, yielding a solution having the same total number of stations as in the previous run of the program but a higher average or maximum travel time.

The Denver research team has developed an algorithm that finds only those configurations that maximize the number of existing stations selected, within the set of all configurations having the minimal number of stations needed to meet the constraints. This substantially reduces the amount of technical manipulation of the program needed to obtain a reasonable collection of configurations to evaluate further.

Data that may have been collected concerning past or estimated future fire incidence in each demand zone are not used in generating the trial station configurations in a Type II run, except insofar as the probability of a fire may enter subjectively into the establishment of travel time constraints. Travel time requirements for units other than the first-arriving one are not explicitly considered in this methodology. This can lead to solutions that are unacceptable to the fire department, although they satisfy all the constraints of the covering problem. For example, in Denver, solutions were produced that placed too few units in the downtown area. Although fire units were acceptable, the times to the additional units that would be needed at a fire in an office building were found to be too long.

One strong advantage that would ensue from complete development of the Type II methodology is that it would incorporate, with some improvements, notions of coverage that are familiar to fire officials in the form of travel-distance constraints. These have been promulgated as standards for many years by ISO, the organization that grades fire departments for insurance purposes. Once a fire department administrator is persuaded of the greater relevance of travel time, he has no difficulty understanding and accepting the methodology. Similarly, the computer-readable street network is used in a way that imitates manual procedures followed by fire departments for many years and, therefore, produces results that have good credibility.

When only Type I runs of the program are used (as recommended by PTI), the PTI methodology is very similar to that used by The New York City Rand Institute in its Firehouse Site Evaluation Model (R10-18). Both models calculate the values of a set of measures that characterize a given configuration of fire companies. The calculations are made assuming that every unit is always available to respond to an alarm. (This is a reasonable approximation in most cities.) The primary differences between the two methods are PTI's use of a road network, NYCR1's explicit weighting of travel times by expected incidence rates (although the documentation is unclear, it appears that the average travel times calculated do not weight the travel time to a given
focal point by the expected incidence there), and NYC-RI's aggregation of travel times by fairly homogeneous subareas larger than a fire demand zone and smaller than the whole city. Although the PTI documentation gives a step-by-step guide to the tasks to be carried out in collecting data and running the programs, it offers little guidance to help the user evaluate various fire station configurations. The most difficult task in determining the number and location of fire stations is to evaluate various options. Although there is some general discussion of this problem (e.g., "the common point of comparison will be the respective capability of site options to satisfy the response time requirements") there is not enough to show how these comparisons are actually accomplished. In fact, the authors state, "with experience the project team members should become very knowledgeable about (the computer program) operation and should be in a position to accurately appraise the implications of policy changes." But no numerical examples are given of how this is to be done or how it has been done in the cities where the package has been used. Although the authors cite several examples of the cost savings that have resulted from the use of the package, the analyses supporting these changes are not given.

It is easy to see the difficulty in comparing alternative site configurations: The demand zones represent different hazards, are of different sizes, and have different numbers of fire incidents. One measure of effectiveness used is the average of the travel times to fire demand zones. But because the demand zones vary in size, this averaging gives more weight to travel times in areas where the demand zones are small—i.e., the travel times in these areas will be counted more times in computing the average. In general, smaller demand zones probably reflect greater hazards so that this method implies some weighting by hazard. But is the relative size of the demand zone a proper weight? The authors of the PTI package do not discuss this issue, apparently not recognizing the problem.

The method used to calculate travel times via the shortest path on a computer-readable network has not been validated against actual experimental travel time data. There is reason to believe the calculation is not accurate for short travel distances, but this may be of no practical interest if the calculation is correct for times near the travel-time constraints. However, it is not known whether this is true.

The total methodology described here has been tested in several cities by PTI, which claims useful, implemented results, and in Denver by an independent group that compared it with alternative methodologies and found it satisfactory except in regard to the details they modified as mentioned above. The Denver team, however, did not use the network approach for calculating travel times between focal points and did not use any of PTI's computer programs directly.

From Public Technology, Inc. city administrators in the United States can obtain computer programs, procedures manuals, and technical assistance needed to carry out this methodology, making it an attractive choice in comparison with other methodologies that would require analytical and programming skills to implement.

R10-18

Abstract: This report provides fire department planners, systems analysts, and data processing personnel with detailed documentation of a computer-based model, called the Firehouse Site Evaluation Model (or "siting model"), that can be used to evaluate alternative configurations of fire-fighting companies. The siting model provides a way to estimate the fire protection levels, measured in terms of travel times, travel distances, and company workloads, that would result from implementation of any given arrangement of fire companies. By comparing the fire protection levels resulting from different arrangements, rational decisions can be made about the deployment of a city's fire companies.

Audience: Fire department analysts.

Issue: How many fire companies are needed and where should they be located?

Policy Utility: Potentially high. See R10-19 and R10-20 for examples of how this model has been used.

R10-19

Abstract: This report presents a description and the results of a deployment analysis of the Yonkers, New York Fire Department. The study focuses on how many firehouses and fire companies the city needs and where the houses and companies should be located. It produces a set of deployment options involving the moving, addition, and elimination of fire companies. The costs and benefits of implementing each option are presented in the report as is a general guide to the methodology.

Issue: How many companies are needed and where should they be placed?

Policy Utility: Potentially high.

External Validity: The methods developed are generally applicable.

Summary: This report presents a description and the results of a study sponsored by the City of Yonkers and the Office of Policy Development and Research of the

1 By comparison with the findings of Kolesar and Walker in R10-6.
United States Department of Housing and Urban Development, and conducted jointly by The New York City-Rand Institute and the Yonkers Fire Department.

The study was occasioned by the fact that the poor condition of several firehouses in Yonkers and proposed routes for new highways through the city meant that some firehouses would have to be vacated. This situation provided an opportunity for the city and the fire department to undertake a comprehensive analysis and reexamination of their fire-fighting resource needs and fire-deployment policies. The study focused on how many firehouses and fire companies the city needed now and five to ten years hence, and where the houses and companies should be located. Based on results of the analysis, sites for two new firehouses have already been chosen and funds for the construction of the houses have been allocated in the new budget.

The study also produced a set of further deployment options involving the addition and elimination of fire companies. The costs and benefits of implementing each option are presented in this report.

An analysis was also made of the manning levels and dispatching policies of the fire department and led to the following recommendations:

1. Send three engines and two trucks to box alarms received between midnight and noon;
2. Send two engines and two trucks to box alarms received between noon and midnight;
3. In either time period, if more than three of the first six engines are unavailable to respond, send one engine to a box alarm and, if two or more of the first three truck companies on the alarm assignment card are unavailable, send one truck company to a box alarm.

The most important methodological aspect of the study was the analysis of alternative firehouse locations. The major steps in this analysis were the following:

1. Data were collected for the mathematical models.
2. Current average and maximum response times were obtained for various regions in the city.
3. Analysis of the response times showed that they did not accurately reflect the fire department's perceptions of the actual hazards in the various regions or the level of protection they wanted to provide. The disparities were that average response times were significantly different in regions representing roughly equal hazards, and maximum response times in some regions were found to be too high.
4. The city specified possibilities for new or relocated firehouses.
5. Resulting response times were analyzed for a large number of configurations of fire companies.

The recommendations contained in this report were presented to the City Manager, the Budget Director, and fire department officials at a briefing in December 1973. Since then, some of the results of the study have been implemented (e.g., two new firehouses have been budg-
age first engine travel time was found to be 1.51 minutes, already lower than has been found in similar cities. But the engines are poorly positioned. A three-phased redeployment of these companies was developed that reduces this travel time to 1.29 and produces a geographic pattern of travel times that is more consistent with the pattern of fire hazards.

(4) Because the current engine travel times were already low, an analysis was made to determine the levels of fire protection that could be obtained with a smaller number of engine companies. It was found that a good deployment of seven engine companies could result in a level of fire protection that is generally better than the city is currently providing with nine engine companies.

The results of the study were presented to the mayor and business administrator, who are currently in the process of working out a proposal for the reconfiguration of firehouses with the fire division. The proposal will then be presented to the city council for its approval.


Abstract: A number of mathematical models are developed for determining the number and location of fire companies. One of these models is applied to the problem of locating fire companies in Fullerton, California. The objective of the model is to minimize the weighted sum of first and second engine response times to all incidents city-wide. The results of the model are compared with the current allocation in Fullerton.

Audience: Everyone, but primarily researchers.

Issue: How many fire companies are needed and where should they be located?

Policy Utility: Medium. Minimizing response time to all incidents may result in inadequate coverage in regions of the city where there are relatively few alarms. Also the analysis is not carried far enough. Although the sites that result from using the model are compared with actual fire company locations, the question of whether locations should be changed is not discussed.

Internal Validity: The analysis generally is very well done.

External Validity: The approach is similar to that of Hogg (R10-15).

Summary: A generally lucid and comprehensive description of the goals and operations of the fire service is given, together with a passing reference to methods for improving performance other than the ones discussed in the paper.

A general location model is introduced, having the following characteristics:

(1) The city is divided by a grid into small homogenous subareas, in each of which the alarm rate is known.

(2) Should a fire station be located in one of the subareas, it is assumed to be at the centroid and its fixed (capital) costs are known. (3) The number of companies of each type that may be located at a station is a policy variable.

(4) For each subarea, the average dollar loss per fire is known as a function of first-due response time. A subjective parameter, \( v \), relates public costs to fire loss costs.

(5) The allowable station sites are some subset of the collection of all subareas.

An "allocation decision" is a selection of a specified number of stations (k), the set of sites for those stations, and the number of companies at each site. Given the above, it is in principle possible to calculate the expected annual total public cost of an allocation decision (manpower plus capital) and the expected annual dollar loss in each subarea. As a slight generalization, it is also permitted that there is a public cost associated with each response to each subarea, this cost being a function of the locations of the units.

The objective of the analysis is to determine the (or an) allocation decision that minimizes \( v \cdot \text{ (private costs)} + \text{ (public costs)} \), subject to a constraint on total public costs.

Within this context, several simplified versions of the model are developed. These ignore fire loss costs as currently unknowable functions of travel time. The first is a warehouse location model, in which the number of stations is fixed, each station has one unit, and the average first-due distance or travel time is minimized. The second minimizes a weighted average of first-due and second-due distances or travel times, where the weight is a subjective measure of the relative importance of second-due to first-due times, varying by subarea. (In the application, the author chose the weight to be the probability that a second unit was needed.)

The third minimizes the maximum weighted first-due time, the weight for each subarea being the probability that a random fire is in the specified subarea.

A constraint on the maximum allowable first-due time to any subarea is handled by adding a very large cost to the objective function for any allocation decision that fails to meet the constraint. If the number of sites chosen is so small that no configuration of that many sites can meet the constraints, the resulting minimum value of the objective function will be enormous.

Compared with the current configuration, any allocation decision represents a cost in terms of closing, building, or expanding stations. A constraint on this cost can be incorporated as described above.

The second simplified model is converted to a linear programming formulation, and a heuristic algorithm for solution called ADAPT is adopted. This algorithm was tested against a true optimization program using data for a part of the City of Fullerton, California, revealing that errors in the achieved minimum did not exceed 0.4 percent. The possibility of noninteger solutions apparently was not a problem in practice.
A lengthy description is given of the procedures used to collect the required data for the City of Fullerton. This includes a travel time vs travel distance experiment, which yielded a linear fit with positive intercept. In the application, this relationship is used with right-angle travel distance between two points to estimate response times.

The results of the optimization program were tested using a simulation model designed by the author to compare various performance characteristics for the existing and proposed configurations. The input data stream for the simulation was a duplication of actual historical incidents. By this means, the sensitivity of the results to parameters and data preparation procedures was analyzed. The optimization program was also used to determine preferred move-ups (i.e., which of n stations should be filled if n - 1, n - 2, ... stations are available). The policy of no move-ups was compared by a simulation with the proposed move-up policy.

The study concludes with a discussion of implications, a description of the time and effort involved in various phases of the study, and speculation about related questions of interest.

Discussion: By virtue of the care with which alternative analytical approaches are discussed, the testing of sensitivity to assumptions and parameters, and the general correspondence between this approach and others developed elsewhere (simultaneously or later), the validity of this paper appears well-established. The mathematical models formulated should be useful for researchers, although the more general (and more interesting) models were formulated only but not used.

In general, the models presented here attempt to minimize the expected response time to all incidents city-wide. This may result in long response times in areas where there are few incidents. In fact, the "optimal" locations for the seven engine companies in Fullerton result in a poor distribution of companies in two respects: One region has long response times, and, in two cases, adjacent companies are located in adjacent grid squares. A better allocation would increase average response time somewhat but improve the geographic distribution of companies.

In considering the question of fire company location, the author fails to take into account two important factors: the hazards in each subarea and geographical coverage. Coverage could be measured by the average of the response times to each of the subareas (grid squares) unweighted by the number of incidents in each subarea. In addition, the distribution of these unweighted response times should also be considered. One approach would be to divide the city into several subregions and, for each allocation, compute the average response time in each subregion.

Given several required and conflicting measures of effectiveness and no satisfactory criteria for combining them, approaching the fire station location question as an optimization problem is a difficult task. This study would have been more useful for policymakers if Mitchell had used his "optimal" solution as a starting point with the aim of improving upon the current fire station locations.

R10-22

Abstract: This report describes a method for the allocation of fire companies to regions of a city. The method avoids the difficulty of predetermining a specific allocation criterion by allowing the decisionmaker to generate allocations for a complete range of criteria through use of a single tradeoff parameter. Among the criteria incorporated by the model are the minimization of city-wide travel times, the equalization of average regional travel times, and the equalization of company workloads. A comparison of the allocations generated by the model with the actual allocation of fire companies in New York City shows that, for one value of the tradeoff parameter, the model produces results that correspond closely to the fire department's allocation policy.

Audience: Researchers, fire chiefs, city administrators.

Issue: How should fire companies be distributed throughout the city?

Policy Utility: High. Provides a framework for evaluating the current distribution of fire companies in a city or other local jurisdiction.

R10-23

Abstract: This review paper describes several station location models and organizes them into categories. "The assumptions of each model, the relationships between models, and possible heuristics and algorithms are discussed. In addition, a methodology of spatial concepts analogous to those used in transportation planning is presented."

Audience: Researchers mostly.

Issues: Survey of fire company location models.

Policy Utility: Of interest to researchers, but low for policymakers since the authors do not discuss the utility of any of the models.

R10-24
Abstract: Calls for service arrive at an infinite server queue according to a mixture of Poisson processes. Service for each process occurs in a number of independent stages; stages are identified by the number of emergency units busy serving the call. Assuming arbitrary finite mean-service-time distributions, the distribution of the number of busy units at any time is determined, and the approach to a steady-state distribution is proved.

Audience: Researchers primarily.

Issue: What is the probability distribution of the number of units busy, given alarm rate and service times?

Policy Utility: Low, this work is mainly of interest to researchers.

R10-25

Abstract: For a fixed number of fire stations, each with a specified response district, the measure of effectiveness for each station's site is taken to be a weighted sum of response distances from the site to all the incidents in the district, where the weights are the total man-hours spent handling each incident. The overall measure of effectiveness is the sum of these for all the districts. It is claimed, first, that each station site is optimal if the measure of effectiveness is minimized over all possible sites for that station and, second, that the optimal site is the man-hour centroid of the district. This concept was applied to six stations in Windsor, Ontario by determining and plotting on a map the location and man-hours expended for each fire that occurred over an unspecified number of years. The value of the overall measure of effectiveness was calculated for the current configuration and for the configuration where each station is at the man-hour centroid of its district. The result showed the possibility of an 18 percent improvement. The paper reports that one station was moved after the study was reported to the city administration, but "it is not known as to what degree the decision . . . was influenced by this report." A method for annual evaluation of existing sites is proposed, and certain limitations of the study are acknowledged.

Audience: Primarily operations researchers.

Issue: Fire station siting.

Internal Validity: Poor. Very limited scope; major conceptual errors.

External Validity: Extension to other cities easy, but of little value.

Policy Utility: Slight.

Discussion: The chosen measure of effectiveness is arbitrary and unsatisfactory, as it does not take into account such elementary considerations as response time (rather than distance), second-due and third-due times (rather than just first-due), and the distinction between a serious fire and one that takes a long time to extinguish. The notion that the measure of effectiveness will be minimized if each station is at the centroid of its district is incorrect since the centroid minimizes the weighted squared distance. Therefore, the proposed procedure is internally inconsistent.

The measure of effectiveness depends on how many incidents are included in the data base, and therefore one year's measure cannot be compared with the next year's. All types of fire equipment appear to be treated as if they were equivalent, which is conceptually erroneous in most cities, even if correct in Windsor. The author does not take into account the fact that response districts would change if stations were moved.

The procedure as described could be applied in the same way in any city, but in the absence of internal validity this would be of little value.

Despite the errors, there is some validity to the notion that the proposed "optimal" locations are in fact somewhat better than existing ones, so qualitative insights from this model may be useful. Otherwise, it is not recommended.

R10-26

Abstract: A model is developed that is used to find the number of fire stations needed to minimize total cost of facilities and fire loss per fire, given restrictive assumptions concerning response districts, travel velocity, service time, and fire losses.

Audience: Fire professionals, but notation is highly mathematical.

Issues: Number of fire stations needed.

Policy Utility: Very low.

Internal Validity: Correct and logical within limited scope.

External Validity: Permits application in wide range of circumstances by explicit allowance for variation in parameters, but validity has not been demonstrated.

Summary: The number of fire stations needed in a city is to be chosen to minimize the total cost (of facilities and fire loss) per fire. Facility cost appears to include capital and manpower expenses. Fire losses are intended to include property losses and the dollar value of life losses. Graphs are given showing the optimal number of stations under a variety of assumptions about the parameters.

Major assumptions include:
(1) Fire stations are so located that response districts are square, all have the same size, and all have the same alarm rate. The station is at the center.
(2) Each fire is served by one company, and only the company whose response district includes the location of
the fire will respond there. If the primary company is busy, the alarm waits in queue for service.

(3) All fire companies travel at the same velocity.

(4) Average service time is 30 minutes. Also (unstated assumption) service times are exponentially distributed.

(5) Fire losses are proportional to the total time spent waiting, traveling, and working at the fire.

(6) All fire units are interchangeable.

The paper suggests some quick approximate ways of estimating the facility cost and fire loss cost parameters. Also, one can assume that the current number of stations is optimal and thereby derive the parameters by inverting the model. Then one can determine the number of stations required in the future by estimating future demand parameters.

The authors acknowledge the unrealistic nature of the assumptions underlying the model but suggest that the insights gained from it are valid anyway.

Discussion: Despite the title, this paper has nothing to say about fire station siting.

Collectively, the assumptions are so unreasonable as to defray any effort to estimate the validity of the model. The primary difficulty with the model is that it is sensitive to an estimate of the average cost of fire loss per hour of waiting plus travel plus service, which is difficult or impossible to estimate from data and is conceptually an inadequate model of the relationship between fire losses and fire department operations. In addition, the service time is assumed to be independent of the number of stations (and thus of travel and waiting times).

The mathematical formula for total cost includes a typographical error that presumably was not present in the equation used to calculate the graphs in the paper. The presentation of graphs covering a wide range of parameters gives the impression of universal validity, which the authors encourage. However, the model does not appear to have been tested against data in any city, nor has it been tried against a simulation model. Considering that fire units are of different types, and a model should indicate how many of each are needed, this model's output fails to be of practical use.

Once a fire service administrator has determined the velocity at which his units travel, his dollar value of a human life, and the area of his city, the number of stations needed is (according to this model) a function of the alarm rates alone. If alarm rates double, somewhat under twice as many stations are needed. This relationship is in contradiction to the findings of most other researchers in this field that, at the alarm rates prevailing in most cities, performance measures are insensitive to substantial percentage changes in alarm rates, suggesting that this model will not be found satisfactory by most administrators.

The sensitivity of the model to unknown parameters, lack of demonstrated validity, and strong indications of invalidity suggest that the model should not be used.

R10-27


Abstract: A procedure is developed for analyzing the need for fire stations and is applied to Prince Georges County, Maryland. The procedure determines the need for a station in a given area by developing a fire problem severity index (a measure of the demand for fire services) and a Protection Profile (a measure of the protection being provided based mainly on response time). Within each area a procedure is then developed for finding the best fire station location.

Audience: Everyone.

Issues: How many fire companies are needed and where should they be located?

Policy Utility: Low. As the authors acknowledge, the study uses insufficient data. Also the method is not fully developed.

Internal Validity: The indices developed are not defined, and the method of ranking the study areas with respect to fire company need is not specified.

R10-28


Abstract: For a model in which two urban emergency units cooperate in responding to calls from a region that may have inhomogeneously distributed demands and complicated travel times, the expected response time to calls for service and the workload of each unit are calculated as functions of the boundary that separates the two response areas. The boundary that minimizes mean response time is determined; it may differ from the usual boundary consisting of points equidistant from the two units. Some boundaries may be dominated, in the sense that another boundary improves both workload balance and response time. The set of undominated boundaries is found.

Audience: Researchers, fire chiefs.

Issue: Which companies should be dispatched to an alarm?

Policy Utility: Low, except in cities where some fire companies are busy more than 10 or 20 percent of the time. In such cases average response times to fires can sometimes be improved by sending slightly more distant companies.
R10-29


Abstract: Given a fire alarm of unknown severity, the fire department is faced with the problem of deciding how many fire companies to dispatch. If too few units are sent, the additional units needed will be delayed. If too many units are sent, the extra units will be unavailable for subsequent alarms while they are travelling to the scene. The problem is formulated as a semi-Markov decision problem. The author shows that the optimal decision, for a given number of units busy, is characterized by a cutoff value $s^*$—e.g., if the probability that the alarm is serious is greater than $s^*$, dispatch two units; if not dispatch one unit.

A simple approximation to the semi-Markov model is developed and it is found that the cutoff value $s^*$ depends, in a very simple way, on the number of units currently busy, the alarm rate, and the fraction of serious alarms in the surrounding area.

Audience: Researchers.

Issues: How many fire units should be initially dispatched?

Policy Utility: Highest for large cities where the alarm rate is sufficiently high that there are benefits from such a dispatch rule. For all cities the results suggest the need for careful consideration of the chance that an incoming alarm signals a serious fire. (See R10-30.)

Summary: The problem of deciding how many units to dispatch is formulated as a semi-Markov decision problem. For simplicity, only the problem for ladder companies is considered, although for engine companies the problem is analogous.

To each alarm in an area of interest, either one ladder or two ladders are dispatched. If one ladder is dispatched and the incident requires a second ladder, there will be a delay until this second ladder arrives. If two ladders are dispatched and, as is usually the case, the second ladder is not needed, for a short time the second ladder will be unavailable for subsequent alarms. Because the second ladder dispatched is unavailable for a short time compared with the first ladder dispatched, the number of busy ladders of each type are differentiated. The first ladder dispatched becomes unavailable-class 1, while the second ladder dispatched becomes unavailable-class 2.

It is assumed that losses occur at serious alarms, which are defined to be those requiring the services of at least two ladder companies, and that these losses depend on the response times of the first and second ladders sent. Alarms occur in the area according to a Poisson process with rate $\lambda$, with the alarm stream consisting of $j$ alarm-types, $j = 1, \ldots, n$. Associated with each alarm type is probability $s_j$ that an alarm of that type is serious. The problem is to specify how many ladders to dispatch as a function of the number of class 1 and class 2 ladders busy and each value $s_j$ and to find the policy that minimizes average loss per unit time.

It is shown that the optimal decision when $i_1$ class 1 ladders are busy and $i_2$ class 2 ladders are busy is characterized by a cutoff value $s^*(i_1, i_2)$. That is, if the probability of a serious fire is $s^* \geq s^*(i_1, i_2)$, dispatch two ladders; if not, dispatch one ladder. This result is used in a linear programming formulation that is solved to obtain the optimal decision rule.

An approximation to the Markovian model is developed by considering a finite time horizon—from the occurrence of an alarm until the second ladder, if dispatched, becomes available. The results using the approximation are found to be close to the linear programming solution. The cutoff value $s^*$ given by the approximation depends, in a very simple way, on the alarm rate; the number of class 1 and class 2 ladders busy; $a$, the relative weight given to first ladder response time; and $E(0)$, the expected probability of a serious fire for alarms in the area of interest. Using a simulation model, this decision rule is compared with traditional fire department dispatching rules and is found to improve response time significantly.

R10-30


Abstract: Four models for estimating the probability that a box-reported alarm signals a serious fire are given and compared: (1) one-stage box history; (2) one-stage empirical Bayes binomial; (3) two-stage empirical Bayes binomial; (4) two-stage empirical Bayes constant over region. Estimates were calculated from data of all alarm boxes in the Bronx before and during 1969 and then evaluated by comparison with 1970 data. Estimates were first compared using a standard statistical test. In addition, estimates were evaluated by comparing the results of dispatching policies based on each of the estimates. Using both the statistical test and the comparison of dispatch policies, it was found that empirical Bayes estimates perform better than estimates based only on the history of the box signaling the alarm, and two-stage estimates are superior to one-stage estimates. That is, in predicting the probability of a serious fire, it is better first to predict the probability of a fire in an occupied structure and then to predict the probability that the occupied structural fire is serious, rather than attempt to predict the probability of a serious fire directly.

Audience: Researchers, fire chiefs.

Issue: How can the likelihood that a box alarm signals a serious fire be predicted?
Policy Utility: Provides a rational way of cutting down unneeded responses at the least risk of underresponse to a serious fire.

External Validity: The approach could be used in all cities, although the accuracy of the predictions has been tested only in New York.

R10-31

Abstract: This paper describes a fast, computer-based method for determining relocations. It will become part of the Management Information and Control System being developed for the Fire Department of the City of New York. The relocation method consists of four interrelated problems, each of which is solved by the use of simple heuristics. A mathematical programming formulation of the problem is given, together with an example, the results of a simulation test of the method, and a description of the current use of the computer algorithm in an interactive time-shared environment.

Audience: Fire chiefs, researchers.

Issue: When and how should relocations be made?

Policy Utility: High for large cities, low otherwise.

Summary: When all the fire companies in a region are engaged in fighting fires, protection against a future fire is considerably reduced. It is standard practice in many urban fire departments to protect the exposed region by temporarily relocating outside fire companies in some of the vacant houses. Situations requiring such relocations arise an average of ten times per day in New York City, and the Fire Department of the City of New York (FDNY) currently makes its relocations according to a system of preplanned moves. This system was designed at a time when alarm rates were low and is based on the assumption that only one fire is in progress at a time. Because of the high alarm rates currently being experienced in parts of New York City, this assumption is no longer valid; and the preplanned relocation system breaks down when it is needed most.

This report describes a computer-based method for determining relocations that overcomes the deficiencies of the existing method by utilizing the computer's ability to store up-to-date information about the status of all fires in progress and the location and activity of all fire companies and to generate quickly and compare many alternative relocation plans.

The method will become part of the FDNY's real-time Management Information and Control System (MICs) and is designed to be fast and to require little computer memory.

The relocation method consists of four interrelated problems, each of which is solved by the application of simple decision rules, called heuristics.

1. When should relocations be made? A call for relocations will be made whenever the fire protection being provided to any area of the city falls below a given minimum level.

2. Which vacant houses should be filled? The houses to be filled are chosen to bring fire protection in all areas above minimum levels while moving as few companies as possible.

3. Which available units should be moved? A function is used to compare alternative relocations. It expresses the "cost" of relocation in terms of response time to future fires. The function takes into account such factors as alarm rates, relocation distance, expected response times, and expected durations of the serious fires. The set of companies that produces the lowest "cost" relocation is selected to be moved.

4. Which specific relocating units should be assigned to each of the vacant houses being filled? The set of relocating units is assigned to the set of houses to be filled so that the total distance traveled by the relocating units is minimized.

After giving some background of the problem and the objectives of relocation, the authors give the problem a mathematical programming formulation and then describe the heuristic algorithm to be used for generating relocations in the MICs. The remainder of the report is devoted to a discussion of an example, a rigorous test of the algorithm using a computer simulation model of fire department operations, and a description of the current use of the computer algorithm by dispatchers in an interactive time-shared environment. Results of testing indicate that the proposed algorithm is a significant improvement over existing methods, particularly in crisis situations.

R10-32

Abstract: This paper reports the results of asking a fire officer questions of the form: At a typical structural fire, would you prefer travel times of two minutes for the first engine and first ladder to travel times of one minute for the first engine and three minutes for the first ladder? Answers to such questions were used to develop a utility function that would, for example, enable one to predict which of two new sets of travel times the officer would prefer.

Audience: Researchers; fire chiefs.

Issue: Is such a distillation of fire-fighting experience reliable and helpful?

Policy Utility: A possible way to integrate response times for several engines and ladders into a single number. It may yield a better weighting of long and short response times than a simple average, as well as a way to average first-arriving engine times with second-arriving engine times and with corresponding ladder times.
Validity: The author acknowledges the speculative nature of this work and mentions some possible pitfalls. They include: the inadequacy of using the responses of a single officer; the extended period of questioning and the possibility that the officer’s answers were guided by the questions; and the vagueness of the “typical structural fire.” This work should be taken as a first, tentative step.

R10-33

Abstract: This report discusses the results of a study of the dispatching operation in New York City Fire Department Communications Offices. The analysis was performed in late 1968 and early 1969. A computer simulator model was developed and used to show that at a rate of about 25 alarms per hour the average time needed to process a fire alarm became intolerably large. The analysis showed that simple and inexpensive dispatching improvements, notably dividing the borough of Brooklyn into two parts for dispatching purposes, significantly reduces dispatching delays.

Audience: Everyone.

Issue: How can dispatching delays be reduced?

Policy Utility: High for large cities.

External Validity: Although dispatching offices differ from city to city, they are sufficiently similar that the results of this analysis should generally hold.

Summary: The elapsed time between report of a fire and arrival of fire equipment on the scene consists of the time needed to process the alarm in the Communications Office (the dispatching time), the fire company turnout time (the time from when the company is notified until the apparatus leaves the firehouse), and the travel time from the firehouse to the scene of the incident. In this report it is shown that when the alarm rate increases, the dispatching time becomes large relative to both turnout time and travel time. Simple modifications in traditional procedure (several of which have been implemented) can lead to important reductions in dispatching time.

The alarm processing procedure consists basically of decisionmaking relating to receipt of an alarm and dispatch of equipment. The course of the research, the then existing processing procedure was represented as a multistage queueing model. After extensive data collection and curve fitting had been done for each operation in the procedure, a computer simulation was run to determine the dispatching time (i.e., time from receipt of alarm to its transmission to field units) for varying alarm rates. The results showed that the expected dispatching time increased slowly up to a rate of about 25 alarms per hour. At that point, the curve became steeper, increasing to over three minutes at 30 alarms per hour, and to approximately nine minutes at 35 alarms per hour; the average is 1.7 minutes at 25 alarms per hour. (At the time of the analysis in the borough of Brooklyn, the alarm rate during busy periods was approaching the steep part of the curve.)

It became clear that the difficulty was at the second stage of the process, the decisionmaking point. Under the traditional procedure, there was only a single channel at that point; i.e., decisions were made one at a time by a single decisionmaker. Furthermore, the dispatch decision became more difficult with the increasing unavailability of equipment, so that the average decision time became greater with the increase of active incidents in the field.

Given this Stage 2 bottleneck, improvements can be made either by reducing decisionmaking time (for example, by providing better unit status information by means of digital status reporting from the field) or by adding a second-stage channel. A second channel can be added by dividing the borough into two parts, with a separate decisionmaker responsible for alarms and units in each half. This notion was tried and proved successful: During one particular test, 27 alarms were transmitted in 30 minutes and 43 in one hour; these totals were higher than had ever been achieved before.

R10-34

Abstract: This report describes a study of fire department communications in the Baltimore Fire Department. It describes the alarm, communications, response, and status-reporting procedures in use. Because the alarm rate is low, the authors recommend that computerized dispatching is not needed. They also recommend a separate frequency for ambulance dispatching and replacing mobile radios with modern solid-state multi-channel equipment.

Audience: Fire department communications personnel, administrators.

Issues: Communications and dispatching problems.

Policy Utility: The paper is of some interest, although its contents suggest the Baltimore Department does not have serious communications problems.

Internal Validity: Generally adequate.

R11-1
Abstract: This report is a summary of “all known operational technology” that currently exists “to enhance the efficiency of the fire service,” with the authors’ thoughts on which areas need improving and an evaluation of existing products. It furnishes small fire organizations with a “basic document to inform them of what’s new in fire technology.”

Audience: City officials and fire chiefs.

Issue: What is the state of the art in fire service technology?

Policy Utility: A helpful reference document that would have been more helpful if it had measured benefits more broadly. For example, the authors point out that infrared heat detectors can save overhaul time. However, in a city with few fires, there are no overall dollar savings from quicker overhaul.

Internal Validity: Adequate.

External Validity: Adequate.

Summary and Discussion: The primary objective of this report, say the authors, is to “examine the modern technology which is available to the fire service to improve its efficiency and effectiveness.” They discuss 11 areas in which they believe technology can be applied productively: fire extinguishing agents; infrared heat detectors; protective clothing; breathing apparatus; helicopters; rapid water; lightweight hose, couplings, and nozzles; short range communications systems; fire engines and related equipment; allocation of resources (fire station location); and explosive entry devices (e.g., Jet-Axe).

Each chapter treats one area in an easy-to-follow format that includes an explanatory introduction, state-of-the-art review of research that has been done or is being done, and details on each of the available devices—manufacturers, cost, effectiveness, advantages, and drawbacks.

The report appears to meet the objectives it sets for itself. It is intended to furnish local legislators, chief executives of cities and counties, and fire chiefs with a summary of what currently exists in fire technologies, while it stresses areas that need improving and aims at providing more effective use of manpower. The authors also address this report to small fire organizations, which, they say, can use it as a basic document. An important feature is the bibliography, which is claimed to be the most extensive available on recent fire technology research.

The authors point out that the fire service has not developed technologically to its full potential and the introduction explores some of the reasons for this, describing industry and fire department characteristics that inhibit the development of innovative products. They go on to give an illustration of a fire department that has been actively involved in research and discuss the increasingly important role of nonprofit research and testing organizations.

R11-2

Abstract: Using examples from many cities, the author shows how duty schedules are constructed and how to calculate average fire duty hours per week. Distinguishes actual duty periods per year per man from scheduled ones, emphasizing the need to know precisely how vacations, holidays, etc. are handled to obtain actual from scheduled. Shows how to calculate the number of authorized positions needed from a specification of the number of on-duty fire-fighters required and the schedule. Indicates extent and influence (and even inconsistency) of state laws restricting firemen’s schedules.

Audience: Fire chiefs, administrators.

Issues: Suggests the options available and shows how to relate authorized positions, schedules, and number of men actually on duty.

Policy Utility: Moderate. Needed for an accurate determination of the budget required to ensure a specified number of men are available for fire-fighting.

Validity: Good as far as it goes, but it does not indicate that men have to be assigned to platoons and groups and then to companies, and that it may be necessary to have men rotate between companies, or how to schedule vacations, and so forth. There is no indication that these aspects are important or difficult. Even though intended for administrators, some suggestion that the problem does not end with schedules would have been desirable for administrators to understand what the fire department faces in this task.

R11-3

Audience: Researchers, fire department planners.

Issues: Equipment replacement in general with fire engine replacement as an example.

Policy Utility: Low. Equipment replacement is not a serious problem. It has not been established whether the benefits of this method outweigh the costs of using the model.

Internal Validity: Generally adequate.

External Validity: An application of data from the Washington, D.C. Fire Department is presented.

Summary: This paper has two purposes. First, it provides a brief description of some of the standard models of equipment replacement that have been published in the literature. The authors then describe their dynamic programming model, which incorporates many restrictions that are not considered by standard models. The
The basic problem is that standard equipment replacement models almost always consider the replacement decision on an item-by-item basis. Following this approach may lead to violation of some real world constraints such as the fact that it may not be possible to replace all items in a given year because of budget limitations or physical changeover conditions. The authors’ model considers this explicitly.

The model of the paper is dynamic programming with constraints. Because of the constraints the model is useful only for a fixed time horizon, and the usual limiting dynamic programming results are not obtainable.

The objective of the model is to minimize the discounted present value of the cost of operating a fleet of fire engines over a specified number of years in the future.

The constraints explicitly accounted for in the case of fire engine replacement are:

1. A minimum number of fire engines required in each period (usually a year).
2. A maximum number of fire engines that can be purchased in each period.
3. A maximum number of fire engines that can be retired in each period.

In addition to these values, the following are required:

1. The age by which engines must be retired.
2. The purchase price of a new engine in each period.
3. The age and number of engines present at the initial decision.
4. The maintenance cost of an engine in each period of its life.
5. The salvage value of an engine in each year of its life.

These data coupled with the model yield a plan of retirement and purchase for each period of the planning horizon. The authors present results of the model applied to the Washington, D.C. Fire Department data. The results are intuitively obvious; if an engine has high maintenance cost, then get rid of it as soon as the restrictions allow. If it does not have excessive maintenance costs, keep it for another year. The authors hint that there may be conditions under which solutions would be simple closed form rules but they have not investigated this.

An appendix contains all of the mathematical details of the model and a listing of a specialized computer code for efficiently solving the model. Also, a separate appendix describes the same model in an integer programming formulation. The authors make no attempt to solve the model this way. The number of variables for a T period problem is \(2T\) and the number of constraints is \(3dT\), where \(d\) is the number of distinct ages in the initial mix of engines. In the five-year example solved by dynamic programming, \(d\) is 15, so the integer linear programming problem would have 150 variables and 225 constraints. There is a lot of structure in the problem and it may be possible to solve it using integer programming.

**Discussion:** This paper provides a model for equipment replacement decisions that can be used in complex situations, and it provides food for thought for anyone in the area of equipment replacement and maintenance theory. The validity of the model is a difficult issue. It is a dynamic programming model for a fixed time horizon and accounts correctly for all costs and makes correct decisions, but it assumes that the decisionmaker is indifferent to the state of the system—i.e., the ages of the fire engines—at the end of the fixed horizon. This may seriously affect its validity, especially for short time horizons. Another question not answered entirely is the dynamic aspect of the nature of the decision restrictions. Situations change from year to year. The model of this paper could be used anew whenever this occurs but the unwary reader may not realize this.

The data requirements for the model are not too extensive but they would be sometimes hard to estimate. For example, the budget allowance for replacement eight years from now can depend on a myriad of factors. Any figure used can be little more than a guess in most situations, especially fire engine replacement, which usually comes out of a municipal budget that is subject to various political and social influences. It is by no means clear that this model provides better answers than a standard economic replacement age model.

R11-4

**Abstract:** This work analyzed operations at 134 (unplanned) fires, in order to learn how to use water, manpower, and equipment more efficiently during a nuclear emergency. It gives correlations—for example, between the man-hours spent on fire-fighting and the maximum floor area burned, and between the amount of water used to control the fire and maximum floor area burned. The correlations and other analyses are used to estimate what proportion of fires different self-help and other civilian brigades could handle.

**Audience:** Civil defense planners, fire chiefs.

**Issue:** What can be learned about fire-fighting tactics from measurements of the effort used on real fires?

**Policy Utility:** Low in peacetime, although the data collection and analysis might suggest ways of relating tactics to fire outcomes.

**Internal Validity:** The validity of using maximum fire area as if it were determined independently of firefighting operations depends on the assumption that "fire size changes relatively little after fire fighting operations begin." This assumption was not tested, and in
nuclear emergencies, when water, manpower, and equipment would be in short supply, it would seem to be false.

**Discussion:** For judging fire tactics, one would like to see how maximum fire area depends on tactical decisions—number of men, water quantity and rate, etc.—for fires that are the same size and growing at the same rate when companies arrive. These conditions are neither controlled nor corrected for in this study. Fire size at arrival was estimated. It might be possible to guess growth rate from knowledge of the structure and contents. There is an alternative simply way to estimate manpower needs for civil defense purposes. If maximum fire area is not much larger than area when companies arrive (as Labes claims on p. 5), then just use the data to estimate manpower needed for control. For example, just add up the number of man-hours used to control the 134 fires. If, in a nuclear emergency, men (and water) are too scarce, some fires will grow considerably and the resulting man-hours needed to control and maximum fire area will be larger. It is not clear what good it does to know that these two quantities stay in proportion as the situation gets worse.

This relationship and the others were obtained by regression, which does not imply cause and effect. The maximum area of a fire that is a given size when companies arrive depends on how many men fight it. In normal times, bigger fires get more men. What would happen if 10 men had tried to handle one of the fires in this study that was fought by 20 is not clear.

Much effort was devoted to simulating conditions at an actual fire.

For most of these operations, four companies (or groups of companies) were chosen and then teams of from three to six men were chosen from each company, making a total of 16 times that the operation was performed. Data on the time to perform the total operation, time to perform parts of each operation, and the typical sequence of events are reported. When unusual events occurred (such as faulty equipment), they were carefully noted and discussed. Physiological effects of the operations (pulse rate, degree of thirst, and exhaustion) are reported.

Some of the operations were totally impossible for the three-man team to perform. Even when the three-man team could complete the operation, it took roughly three times as long as the six-man teams. In almost all cases, the three-man teams were so exhausted at the end of the scheduled operation that they would have been incapable of participating in the rest of the fire-fighting operation. Only a few of the eight operations could have been performed by the four-man teams in a manner satisfactory to the observing battalion chiefs. The five-man operations usually were satisfactory and took only about 20 percent longer than the six-man operations.

**Discussion:** This paper should be of interest to all fire department management personnel involved in determining manpower levels. In addition, the data might provide the start of a model of the effect of manpower on fire-ground operations for eventual incorporation into a computer simulation. The experiments were worked out in detail to eliminate variation in the work performed between teams. Much care was taken to simulate actual fire-ground conditions: the inside of the building was kept in darkness; the men had to wear masks and full fire-fighting clothing; the men did not know in advance what operation was to be performed. One problem is noted in the report. The Dallas Fire Department uses only five-man companies and in some of the six-man tests the officers had some difficulty in utilizing the extra man. Consequently, the results for six-man teams may underestimate how effective such teams would be if they trained and worked together before the experiment.

**R11-5**

**Abstract:** An experiment was performed to determine the relationship between fire ground effectiveness and fire company manning. A series of operations were performed using companies of three to six men. Data were collected on the time to perform various tasks and physiological effects were measured.

**Audience:** Fire chiefs, researchers.

**Issues:** Number of firemen required for fire ground operations.

**Policy Utility:** High; an example of the kind of research that is needed.

**Internal Validity:** Good.

**External Validity:** Adequate. Care was taken to simulate actual operations.

**Summary:** Eight operations typical of actual firefighting operations were chosen for the experiment. The operations involved from one to three companies. In some instances, only one company was involved in the experiment, but the operation was to perform the work of a company working with several others at a large fire.

**R11-6**

**Abstract:** Fifty-six experienced full-time firefighters assigned to ladder companies were trained to operate a 1958 Mack pumper apparatus. Task and problem solving performance was measured at the end of an initial training period and at the end of one, two, three, and
four month intervals without review or training. Task and problem solving performance with the benefit of hands-on-practice, operations manual review, sound-on-slice review, and video tape review were also evaluated at the end of a four-month period without such practice or review.

**Audience:** Fire chiefs.

**Issues:** The effect of continued training on pumper related fire-fighting skills.

**Policy Utility:** Medium. Establishes degradation rates of certain fire-fighting skills critical to formulating periodic retraining programs for fire-fighters.

**Internal Validity:** Statistical procedure is good.

**External Validity:** Similar results should hold in any fire department.

R12-1

**Abstract:** Existing agencies will submit reports, through the NFPA, to this system. The reporting agencies include state fire marshals’ offices, insurance organizations, certain hospitals, and home survey projects. The emphasis is on data that will be useful for fire research, in particular research on casualties and losses in residential fires. Since data may not be available for all states, certain fire departments within nonreporting states will be selected as the basis for a statistical extrapolation to the entire state. Data from hospitals and home surveys will likewise be extrapolated. For incident data, NFPA codes will be used whenever possible. It is expected that states and local departments will be encouraged to cooperate by the prospect of receiving regular statistical summaries of their data. The system is output oriented. Records will be kept on an incident by incident basis. When a request for a report is processed, the relevant sections of the files will be read and tabulated. Output will be oriented to the federal government, the NFPA, and to local government in that order.

**Audience:** City, state, and national administrators; fire chiefs.

**Issues:** Specify a national fire data acquisition and reporting system. Estimate unknown data.

**Policy Utility:** Potentially high. If appropriate data are gathered, a valuable information source for the researchers, legislators, etc. would be available.

**Internal Validity:** The work has two weaknesses. Once a preferred source is chosen for an item, similar data from other sources are ignored. Also, there appear to be better alternatives to some of the procedures for estimating missing data.

**Summary and Discussion:** The goals of the system are that it will be comprehensive and complete and that it will have its primary focus on fire casualties and residential fires. An ambitious attempt is being made to gather data from several sources including state fire marshals’ offices, home surveys, certain hospitals, insurance organizations, etc. For completeness, where fire incident data are nonexistent because there is no state reporting center, or other detailed data are unavailable, sampling techniques similar to those used in polling are being adopted.

In any such undertaking, there are two complementary problems. How do you resolve conflicts between two sources of data, and how do you fill in missing data? The answer proposed for this system to the first question is less than adequate. Where the same data are available from more than one source, only one preferred source is used. The rest are ignored. There appears to be no mechanism in this system for resolving or even pointing out conflicts.

The statistical extrapolation technique seems reasonable where complete data for a given state, for example, are unavailable. In these states a sample of “fill-in” fire departments would report directly to the NFDS center. However, there appear to be alternatives to their combinations of the extrapolation and data. For example, in order to collect national fire injury counts, data from a sample of 119 hospitals are to be used to estimate the number of fire injuries treated in all hospitals, with fire department records to be used to estimate the number of injuries not treated at hospitals. A reasonable alternative would be to use the number of injuries reported by fire departments, to correct for any estimated undercounting within a city, and to add estimates for nonreporting geographic areas. Auerbach seems rather sanguine about the statistical accuracy of its extrapolation technique but offers no mathematical justification.

A shortcoming in this proposal, common to the others we have seen, is that there is no conception of what data would be useful for research purposes. The stated focus is on casualties and residential fires, yet no special care has gone into ensuring that adequate and useful casualty data will be collected. The NFPA 901 casualty coding specifications are being used, and these are quite sketchy compared with what is being collected in New York City on fatalities.

About 2 percent of the incidents will have a detailed investigation record. This record will contain information (such as estimated delays, number of companies responding) that has proved useful in deployment analysis. However, 2 percent of national fire incidence is less than the number of records collected in New York City alone.

Looking at the British experience (R7-7, R7-8) with the data needed to develop relationships between response time and casualty risks, it seems that a massive amount of detailed data is necessary to wash out extraneous factors that introduce noise. The statistical extrapolation used by this system would seem to ensure its lack of usefulness for this purpose.
It is possible that for some purposes the data collected will prove useful, as in pointing out areas for further research. It is not clear that this system is capable of providing a primary source of research data.

R12-2

Abstract: The advantages of a uniform incidence reporting system are discussed. Fire reporting forms are described: alarm, field incident, company incident, fire investigation, and fire casualty reports. Several output reports are also described: the summary of incidents by district, total number of alarms and loss, number of alarms by source, number of fires and loss by property class and district, summary of activity by company, number of fires by property class and area of origin vs. source of heat, material ignited, act or omission, listing of fire incidents with greater than X dollars, listing of deaths and injuries, utilization of resources by district, and selected fire statistics. Part 2 of the manual lists numerical codes in detail.

Audience: Primarily fire department personnel.

Issues: How to collect fire incidence data in a flexible form useful to local government and yet sufficiently uniform for use on the national level.

Policy Utility: Potentially very high. The standardization of fire terminology and incident reporting and the collection of national data in compatible form are requisites for any federal intervention in the fire problem. Appropriate data, conveniently summarized at the local level, would reduce paperwork and facilitate deployment analysis. However, not enough attention has been paid to what data to collect, so it is less useful for research than it should be.

Internal Validity: The incident coding is based on NFPA-901. There is no evaluation of the utility of these codes, whether anything else should be coded, or whether any of the codes should be modified.

Discussion: The heart of any information system is the data that are collected. There are two common approaches to the collection of data: the first is to figure out what you need for various purposes and then collect it, the second is to collect what is available and then figure out how to use it. The second approach is taken in this report.

In general, the 901 codes tend to be industrially oriented. Flexibility is claimed for the adaptation of this system to various localities, but aside from the choice of using a "utilization section" vs. a "company incident report," the only flexibility is in the choice of output reports. The reports required for input may be too extensive for many cities.

The output reports generated by this system are of the "monthly summary" type. The analysis of data from the reports is of the "spotting trends" and "locating problem areas" variety. The term "cost effectiveness" is badly misused in one section. Many of the reports display dollar loss prominently. However, these data may not be available in many cities.

The modular construction of the data processing system appears sound.

R12-3

Abstract: Several objectives for information gathering are set out: to define the extent of the fire problem in a given area, to define fire department responsibilities with respect to problem areas, to be able to compare different areas, and to accumulate data required for research. Several charts depicting the data to be accumulated are shown. The data classes are: basic fire department resource statistics, fire department budgets, fire incidence data, fire department personnel data, and a fire department equipment profile.

Audience: City and state administrators, fire chiefs.

Issue: To establish specifications for statewide reporting of fire incidence data and fire department resource data.

Policy Utility: Moderate. An adequate data base could help state management evaluate the need for additional fire-fighting resources. Data would be made available for fire safety research.

Internal Validity: This paper follows the usual pattern of presenting long lists of data to be collected without justification. No reference is made to the NFPA codes, and it appears that the proposed data base would be far too incomplete to be of use for research. It is interesting, however, that maximum and average response times are called for. This is the only paper we have seen that specifies such information.

R12-4

Abstract: A very brief description of the overall municipal information system is given. How data are entered and what the TV screen output looks like are described in detail. The output includes building hazards, sprinklers, exposures, and so forth and is available on a real-time basis to assist fire-fighting operations.

Audience: Fire Department management and supervisory personnel.
Issues: Is it possible to reduce duplicate record keeping and improve information sharing at the local level?

Policy Utility: Potentially high. The real-time information on building hazards, fire hydrants, and exposures might improve fire-fighting operations and reduce losses.

Internal Validity: The only type of information this report is concerned with is building data. No mention is made of collecting fire incidence records or any other kind of data useful for deployment analysis. In the area to which it is restricted, the system may provide useful data on-line to personnel responding to a fire. There is no justification for this assumption within the report, however. It is by no means a complete information system as the title might lead one to expect.

R12-5

Abstract: Cambridge, Massachusetts was selected as a moderate sized city with available data and a receptive fire department. Fire incidence data from department records and structural data from Sanborn maps were collected and merged.

Statistical analysis reveals that the relative frequency of alarm type varies significantly by season and time of day. The company workloads are found to vary significantly. And a slight relation is found between light precipitation and structural fire.

Audience: City administrators, fire department personnel.

Issue: Is an information system for geographic fire incidence and analysis economically and technically feasible?

Policy Utility: Low. The paper does not critically examine what data would be useful to collect.

Internal Validity: The study does demonstrate sufficiently that it is feasible to collect incidence and structural data. The analysis of incidence patterns is a pro forma exercise in using the data collected.

R12-6

Abstract: This paper presents the characteristics of 3464 fires, nearly all those in the United Kingdom in the four years 1965-1968 where direct losses exceeded £10,000. It gives the number of these large fires and average loss per large fire for different occupancies, ignition sources, times of day, days of the week, building age, building height, etc. Loss per large fire is more or less independent of age of building, time of day alarm is turned in, day of week, and attendance time. It goes up with building height, hose streams used, and time to control the fire. Fire protection devices do not decrease the loss per large fire.

Audience: Everyone.

Issue: What are the characteristics of large loss fires?

Policy Utility: Slight. Some characteristics of large fires are given but neither the data nor the analysis are useful for policy. For example, the average loss per fire appears not to increase with attendance time (which is the time from receipt of the alarm until the first fire company is on the scene). But only large fires are considered, so the possible reduction in the number (or proportion) of fires that get large that might result from faster response is ignored. Even for factors that do count, it is a long way from policy, because the extent to which identifying these factors lead to cost-effective policies is not clear. For policy, it is necessary to know how much arson losses would be reduced by the authors' call for "strengthening of measures aimed at early detection, i.e., automatic detectors, security patrols, etc."

Internal Validity: The question of validity is not relevant since policy utility is low.

Discussion: Leaving out the fires that are not large means that one can see only the relative loss, given that a fire is large, and not the total picture, which considers how often fires get large in each circumstance.

The points made in the discussion of the characteristics of these fires are reasonable but can be made without these data. There is no need for a table showing average loss in fires that extended to other buildings is larger than loss in those that do not conclude. "This emphasizes the need in fire protection problems to take into consideration the hazard not only due to 'origin' but also due to 'exposure'."