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THE DEFENSIBLE SPACE FACTOR STUDY: A SURVEY INSTRUMENT FOR POST-FIRE STRUCTURE LOSS ANALYSIS [1/]

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ABSTRACT: Structural losses in wildland fires may be expected to increase with further development in the urban-wildland interface. These losses can, however, be minimized by efforts on the part of homeowners and builders to reduce structural vulnerability. The Defensible Space Factor Study, initiated by the California Department of Forestry and Fire Protection in 1989, collects information on wildland fires where structures have been lost or threatened. The goal of the study is to support statistical and analytical research efforts to characterize structure ignition mechanisms and identify effective hazard mitigation measures. Preliminary examination of data collected for the study has highlighted differences in data collection needs for fire incident reporting and more extensive investigations for research analysis. The focus of the survey instrument is on factors previously identified to be associated with structure damage: fire intensify, vegetation clearance, roof type, and defensive actions. A notable application of the Defensible Space Factor Study was its modified use on the Santa Barbara "Paint" Fire in June 1990. An extensive data collection effort, hosted by the Santa Barbara County Fire Department, was directed at the 902 major buildings destroyed or threatened by the fire. Observations and preliminary tabulations on the fire are generally consistent with the findings of previous urban-wildland interface structure loss studies. Some surprising results, however, indicate that valuable new information can be obtained from the remains of devastating fires if thorough and systematic post-fire data collection is performed on both damaged and threatened, but undamaged structures.

INTRODUCTION

The problem of fire spreading from wildland and forested areas into areas of human habitation and structural development (urban-wildland interface) has received substantial attention over the past decade (National Fire Protection Association 1987). The California Department of Forestry and Fire Protection (CDF) initiated the Defensible Space Factor Study in 1989, motivated by mounting concern over structural losses in interface areas. The immediate objective of the study is to investigate and document incidents where wildland fires threatened, damaged, or destroyed structures. In the long term, it is hoped that the study will facilitate assignment of greater responsibility for hazard mitigation to interface dwellers, similar to that now being assumed by developers of high-rise buildings. The Defensible Space Factor Study (DSFS) will therefore attempt to identify which measures in building construction, site maintenance, and defensive actions are most effective in reducing structure vulnerability to fire. Data have been collected state wide on 1,500 structures, over half from the Santa Barbara "Paint" fire in June, 1990. This paper reports on the major elements of the survey instrument used for data collection in the study.

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Butler (1974) was one of the first to extensively describe the urban-wildland fire interface problem in a broader context beyond the scope of a specific conflagration. He defines it as where a fire moves from a wildland environment, consuming vegetation for fuel, to an environment where structures and buildings are fueling the fire. For the purpose of structure hazard assessment, it makes little difference whether a house threatened by wildland fire is located in rural Maine or the city of Los Angeles. The term "urban-wildland interface" may carry an urban or suburban bias, but as Davis (1988) notes, the problem extends across a broad range of development densities and structure distribution patterns. Davis is not alone in predicting that the problem will grow over time. Pyne (1987) went so far as to suggest that this structure loss problem may become the "problem fire" for the turn of the century.

Although not a new problem (Wilkins 1948; Storey and Dieterich 1965), urban-wildland interface fires have recently been the focus of renewed research efforts worldwide. Wilson and Ferguson (1984, 1986) looked at structure survival in Victoria during one of the 1983 Ash Wednesday series of fires which took 76 lives and destroyed over 3,463 structures (in one day!). Ramsay et al. (1986) and Abt et al. (1987) focused on structure ignition. All three studies took a statistical approach analyzing data from actual fires, to establish multifactor associations between structure loss or ignition and a variety of explanatory variables. Cohen (1991) and LeVan et al. (1991) are working on an analytical approach to quantifying the relationships between hypothetical wildland fire exposure and the ignition potential of existing or proposed structures in the urban-wildland interface. The factors involved with structure damage in wildland fires are legion, and their interrelationships complex. Full scale experimentation - which is possible for both structure fires and wildland fires independently - is infeasible for urban-wildland interface fires. Collecting information from recent structure loss situations is, realistically, the best means of observing how structures perform under actual wildland fire exposure.

DATA COLLECTION NEEDS

The extent and severity of the problem needs to be continuously and comprehensively tracked through basic fire incident reporting. Unfortunately, the fire service and land management agencies lack a uniform method to report and track wildland fires and structure losses on them. A National Fire Incident Reporting System designed for structural fires has, however, been in operation for over a decade. This system, based on the Uniform Coding for Fire Protection (National Fire Protection Association 1990a), currently contains the data elements needed to track the extent and basic nature of structure losses at the urban-wildland interface. The California State Fire Marshal (1990) has expanded this data collection locally with the California Fire Incident Reporting System which includes data elements for wildland fire size, national fire danger rating system fuel model, wind speed, fire hazard severity zone, etc. Information on urban-wildland interface fires in this type of database could provide valuable support for building code development, research, and fire prevention recommendations. Williamson and Fisher (1982) have already used the National Fire Incident Reporting System to develop realistic research scenarios for fire exposure to exterior walls of residential dwellings.

The routine reporting of structure losses on wildland fires may also serve to highlight the magnitude of the problem and lead to increased research in the area. The predominant focus of structural fire research is on urban scenarios even though the basic mechanisms studied, for example in exposure fires (Oleszkiewicz 1990), are often similar to urban-wildland interface problems. If the severity and extent of the problem is shown to be substantial through routine reporting, the focus of future structural fire research may be expanded to include urban-wildland interface scenarios.

However, the knowledge level of data collectors and resource availability limit the amount of information that can be collected in routine incident reporting on <u>every</u> structure destroyed or damaged by wildland fire. Furthermore, extensive data collection in addition to that for routine reporting is necessary if research is to shed light on the mechanisms of structure ignition and to identify effective hazard rnitigation measures. This can be accomplished if a detailed survey instrument is put into use on a limited number of fires selected for research oriented data collection. While there is substantial overlap between data collection for incident reporting and for research, the latter must be extended to include undamaged structures threatened by fire. Otherwise, meaningful statistical analysis is impossible. The present DSFS survey instrument combines both data collection orientations and is intended for use on every incident where structures are threatened or lost in California over a four year period.

A third data collection focus prevalent in an earlier version of the DSFS survey instrument (CDF 1989) is compliance with legal codes and/or fire prevention recommendations. Minimum access road width, as an example, is frequently required or recommended in urban-wildland interface areas to permit fire service vehicle access for defensive actions. While a data element on road width would measure compliance with road construction standards, and be useful in characterizing the defensible space around a structure, it would not necessarily be useful in statistical structural loss analysis. For an association between road width and structure loss to be shown, additional data elements on (at least) the presence of fire apparatus and width of the fire apparatus attempting to make access on the road would need to be collected. For structure loss analysis it is more efficient to have a single binary data element on whether or not fire service defensive actions were taken at a structure. Why such defensive actions may not have been taken is a valid, useful, but entirely different line of inquiry which may or may not be included in the data collection goals and objectives. The breadth of potential factors that could be included in a survey instrument is enormous. Establishing the goals of a study, the objectives of a data collection effort, and the intended use of each data element is essential. The primary factors that have been identified as relevant to urban-wildland interface structure losses are discussed in this paper. Further detail on the range of factors and data elements that have been addressed is available from data collection survey forms (CDF 1989, 1990).

STRUCTURE LOSS ANALYSIS FACTORS

Structure Damage

Extent of structure damage from wildland fire exposure is the dependent variable for most kinds of statistical analyses of structure loss. The DSFS presently recognizes three structure damage categories: destroyed, damaged, and threatened but undamaged. A continuous measure of damage, such as percentage of assessed valuation, would facilitate using more powerful statistical methods, but only at the expense of straightforward interpretation of the results, readily satisfied assumptions about the variables, and ease of data collection. Problems with the DSFS's categorical damage classification scheme were, however, evident on the Paint fire. A combination of the classifications used by Ramsay et al. (1986) and those in the California Fire Incident Reporting System (California State Fire Marshal 1990) in which ignition and non-ignition damage is differentiated and several levels of damage categorization are included merits further study.

Differentiation between destroyed and damaged structures was relatively easy on the Paint fire, with only 7% falling into the latter category. The extent of structure damage is often collapsed into a binary coding for data analysis and interpretation. It is worth noting, however, that cross tabulations of damage can be significantly affected by whether damaged structures are compiled with threatened or with destroyed structures. From a fire loss prevention stand point, structures surviving wildland fires with minor damage can be considered as successes for fire protection agencies and hence it is reasonable to group threatened structures in a "survived" category (e.g., Wilson and Ferguson 1984). On the other hand, structures with even minor damage resulting from ignition might reasonably be grouped with destroyed structures in a "burned" category (e.g., Abt et al. 1987), where the presumption is that once ignited a structure would be destroyed without defensive actions (Ramsay et al. 1986). Because the likelihood that defensive actions will be taken cannot be reliably predicted, LeVan et al. (1991) argued that they do not aid in quantifying ignition potential for particular structures. For this type of analysis structures with non-ignition thermal damage (e.g., cracked or broken windows) must obviously be excluded from the "burned" category. Such damage does, however, offer valuable data on potential ignition mechanisms and weaknesses in a building's structural characteristics.

Fire Intensity

Fire intensity is the environmental factor most commonly associated with structure loss in wildland fires. Many environmental factors measured for structure loss analyses such as the DSFS (e.g., fuel and topographic features) influence fire intensity, and are (or can be) used to make qualitative estimates of fire intensity. Previous structure loss surveys (Abt et al. 1987; CDF 1989) have assessed fire intensity with a single question on crown fire presence. As a result, it was impossible to ascertain- what fire intensity a structure was exposed to if it was not located in a forest area. Qualitative indicators of a high intensity fire, such as presence of a crown fire, are useful in some situations, but they do not allow for comparison among structures in different fuel types nor those exposed to the lower ranges of fire intensity. If used in addition to a general measure of fire intensity, questions intended to identify the presence of any large heat flux near the structure can be useful in explaining the ignition or loss of a structure that otherwise would have been expected to survive. The nature of the heat source, whether a nearby outbuilding or a burning vehicle, is not as important as determining the presence of a heat flux greater than would be expected from the surrounding fuel.

Several quantitative measures of fire intensity are possible for post-fire structure loss analysis. The most relevant definition of fire intensity is that put forth by Byram (1959); that fireline intensity is the rate of energy release per unit length of fire front. Van Wagner (1973) established a relationship between fireline intensity and crown scorch height that can be used to estimate fire intensity levels. Wilson and Ferguson (1986) used 1:5,000 and 1:10,000 scale aerial photographs to delineate areas of no observable crown scorch, partial tree height scorch, full tree scorch, and crown defoliation. Based on a similar fire intensity-crown scorch height relationship, they were able to establish four fire intensity level categories for analysis.

Byram. (1959) offers another quantitative measure with the relationship of fireline intensity to the rate of fire spread, amount of fuel consumed in the fire front, and heat of combustion for that fuel. This method was used in the analysis of the 1989 Tiger Fire in Colorado (National Fire Protection Association 1990b) and by Wilson and Ferguson (1984). Two potential sources of calculation error should be considered if this method is used. The rate of spread used in the relationship is that for a line fire moving steadily through a fuel bed. Rate of spread estimates for wildland fires are usually derived from a collection of fire front location observations, which results in a total rate of spread figure that includes fire spread by spotting. In cases such as the Paint fire where there was substantial spotting, using total rate of spread in the relationship over-estimates fireline intensity. Similarly, fuel consumption estimates usually reflect total consumption rather than combustion in the fire front. This would also over-estimate fire intensity to the extent that there was substantial glowing and smoldering combustion after the fire front passage.

Johnson (1982) describes the use of visual flame length observations to estimate fireline intensity, which is the only way to visually assess intensity on wildland fires. Unfortunately, the measurements are rarely taken by trained observers and individual point observations are not replicated. Johnson cautions that "flames are random, pulsating, transient phenomena ... and ... instantaneous or average values for flame lengths are not necessarily representative of the quantity used to derive its relationship with intensity." Despite these shortcomings a flame length observation by residents or fire fighters is the only method to estimate fire intensity at a specific location for the desired point in time (i.e., when the flaming front of a fire passes a structure). It is also the only measurement of the fire that can be readily captured in a survey data element making it especially useful for routine incident reporting data collection. While the potential exists for a continuous measure of fire intensity with flame length, a categorical measure with six or eight categories is potentially more reliable.

Vegetation Clearance

Vegetation clearance, specifically brush, was one of the earliest factors to be correlated with structure loss in this country (Wilson 1962), and it has been consistently recommended in public fire safety literature. Vegetation clearance was also found to be related to structure damage in the 1983 Australian fires (Wilson and Ferguson 1986; Ramsay et al. 1986) and the Florida Palm Coast Fire in 1985 (Abt et al. 1987). Unfortunately, it proved to be a difficult factor to accurately quantify in the DSFS. A single clearance distance measurement for all types of vegetation is, in general, insufficient to fully characterize the hazard that vegetation surrounding a structure presents. Observations on the Paint fire revealed that individual specimens of garden or landscape vegetation planted adjacent to a structure can be a significant hazard. On the other hand, much landscape vegetation clearly does not pose a hazard to structures. Wildland vegetation, of course, varies greatly among fuel types in the degree of hazard it creates for structures. Vegetation characteristics related to structural hazard in addition to clearance distance include: fuel loading, fuel moisture content, heat content, fuel bed height and continuity. The frequently raised distinction between "native" and "ornamental" plants adds little to the hazard assessment if the vegetation fuel characteristics are adequately described. The problem, however, is that full characterization of the vegetation is not possible with post-fire data collection. Vegetation species (or taxonomic) identification in conjunction with height and clearance distance data would be useful in evaluating the hazard, providing that relationships could be established between taxa and the vegetation characteristics of interest such as fuel loading. It was decided, however, that the knowledge, training, and time required for this level of data collection was not feasible for the DSFS. Species group data was collected by Wilson and Ferguson (1986) but not included in their model of structural survival.

The DSFS assessment of urban-wildland interface vegetation is based on a specific qualitative exclusion of "non-hazardous" vegetation from consideration with height and clearance distance estimates made for the remaining vegetation. Much of landscape vegetation is, by its nature rather than clearance distance, non-hazardous to a nearby structure. The exclusion of this vegetation from clearance distance evaluation prevents non-hazardous landscape vegetation from being lumped in with clearly hazardous vegetation, the combination of which would confound structure loss analysis on vegetation clearance. The degree of hazard is evaluated with vegetation clearance distance measurements for each of four separate horizontal strata of vegetation height: less than 1.5 feet; 1.5 to 3 feet; between 3 and 10 feet; and greater than 10 feet tall. This assessment relies on the data collector's ability to consistently determine which vegetation to exclude from consideration in measuring vegetation clearance distances around structures. This proved difficult on the Paint fire and during that incident the survey instrument decision criteria were formed into a decision tree, shown in Figure 1, to assist in consistent data collection. The criteria are based on California's Public Resource Code (PRC 4291) requiring vegetation clearance around structures in the wildlands. One potential problem for analysis is that the criteria encompass a dual evaluation, recognizing both the potential heat flux from the vegetation and the ignition susceptibility of the nearby building structural components.

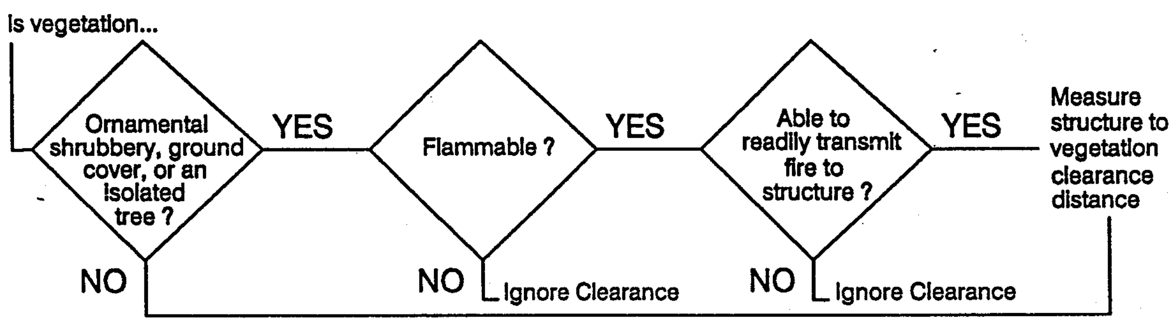

Figure 1. Decision criteria for exclusion of garden or landscape vegetation as non-hazardous for vegetation clearance distance evaluation.

An interesting point to note is that data collectors on the Paint fire, many of whom had years of experience enforcing PRC 4291, expressed frustration that structures which they felt would have passed a routine vegetation clearance inspection, had vegetation near the structures which was included in the survey because the vegetation could (did?) readily transmit fire to the structure. A decorative juniper bush planted next to the front door of a suburban home may fall within the scope of existing legal codes requiring vegetation clearance around urban-wildland interface structures. That type of vegetation, however, rarely falls within the scope of existing code enforcement by either wildland or urban fire service agencies, despite the apparent hazard of such vegetation.

The role that vegetation plays in a structure's vulnerability during wildland fires is neither clear-cut nor easily characterized. The conventional wisdom, reflected in the above discussion, is that reducing the volume of vegetation around a structure reduces the potential heat flux that would threaten that structure.

However, Wilson and Ferguson (1986) hypothesized that if the vegetation between a structure and an approaching fire is not readily combustible, it may serve to protect the structure by absorbing a portion of the heat flux and by filtering out firebrands. This would be especially true for trees. An alternative scenario is suggested by the results of studies on firebrand production and transport from full scale experimental house fires. Vodvarka (1969) found on two occasions that firebrand fallout densities were much higher on the leeward side of trees. On one burn 97% of the 2,325 falling firebrands recorded during a fire, as indicated by holes melted in large plastic sheets laid on the ground, landed just downwind of a large tree. Vodvarka implied that these trees caused leeward eddies resulting in greater firebrand fallout. Which would, in the case of trees between a structure and an approaching wildland fire, increase the threat to structures rather -than protect them. Both scenarios are supported by depictions of wind profiles over vegetation windbreaks, where the shape of the vegetation is a dominant factor the occurrence of leeward eddies (California Association of Resource Conservation Districts 1980).

Roof Type

Roof covering (cladding) is the structural element that has consistently received the most attention in evaluating ignition potential of structures exposed to wildland fires (Wilson 1962; Foote et al. 1991). It has also been shown to be significantly associated with structure ignition or loss in statistical analyses (Wilson and Ferguson 1986; Ramsay et al. 1986). Roof coverings are grouped into general categories for data collection in the DSFS with the exception of fire-retardant (FR) pressure-treated wood shingles ("wood shingle" in this paper includes sawn shingles and hand split shakes). This level of analysis coincides with that of the California Fire Incident Reporting System (California State Fire Marshall 1990) and is consistent with Uniform Coding for Fire Protection (National Fire Protection Association 1990a). However, the present level of data collection on roof type may not permit the detailed analysis that many see as needed for this critical factor.

Foote et al. (1991) describe roof type data collection on the 1990 Santa Barbara Paint fire. That paper includes an example of a well documented firebrand ignition under a concave tile roof, providing anecdotal evidence of how a structure with a fire resistant roof can still be lost. Insufficient detail on roof type in this case prohibits analysis comparing concave tiles with flat tiles, or concave tiles with and without firestopping, due to the consolidation of. concave tiles; flat tiles; tiles made of clay; concrete; lightweight concrete; and fiber-cement into a single roofing category ("firestopping" refers to bird stops or cement filler that block the eave openings under concave shaped tiles limiting firebrand entry and preventing accumulations of fuel such as bird nests and leaves). Additional Paint fire data collection on roofing and other factors from building department records or resident questionnaires is being considered. A more detailed initial data collection for the future is also being planned. The added value of expanded data collection must be weighed against the effort required, both in data gathering time and training, to obtain the information. One non-fire service observer on the Paint fire, upon examining a completely destroyed and leveled structure, remarked that there must have been a pottery or ceramics shop located there. He had mistaken the remains of a tile roof for broken pottery. This is a reasonable mistake and one which illustrates the value of training for data collectors and of structural fire investigation experience. After a week of data collection work on the Paint fire, most observers could readily identify product-specific noncombustible roofing material.

Combustible roofing material is not, however, as readily found or identified after a fire. On the Paint fire, it was impossible to distinguish among FR untreated wood shakes, FR pressure-impregnated wood shakes, and shakes with a lower level of FR treatment such as chemical coating (Foote et al. 199 1). A data element category was provided in the survey instrument to capture the information, but there was usually no way to identify FR pressure-impregnation treated shakes in the field. This problem could be remedied for research data collection by screening wood shingle samples in the field for presence of FR chemicals. A colorimetric test is available for this purpose (Committee For Fire Safe Roofing 1989) that is inexpensive and takes less than five minutes to complete. A positive result from this test would only indicate that the sample was likely to have been FR treated by either a chemical coating process or a pressure-impregnation process. Only the latter is judged to be an effective process for exterior applications (Richardson 1990). Those structure sites that had positive samples in the screening above would then be selected for additional wood shingle sample collection and/or extensive examination by well trained structure fire investigators. The additional samples could be sent out for laboratory testing to ascertain the degree of FR treatment present. Until pressure-impregnated FR treated wood shakes become common, this process would not be overly burdensome. It would provide, for the first time, quantified data on the response of structures with pressure treated shakes to full scale realistic fire exposure.

Defensive Actions

The Australian multifactor analyses done by Wilson and Ferguson (1986) and Ramsay et al. (1986) show that in addition to environmental and structural factors, occupant defensive action is statistically associated with structural survival. When wildland fire suddenly threatens a home defensive action is often the only course of action available to an occupant to affect the outcome of the fire. Data collection focusing on the relative effectiveness of different types of defensive actions could produce useful self-help advice for urban-wildland interface residents.

LeVan et al. (199 1) point out that while defensive actions may be important in structural survival, their occurrence cannot be accurately predicted. This will greatly complicate predictions of site-specific exterior fire exposures until a tool to measure potential private defensive actions is available (interior private fire protection measures and public fire protection potential is currently measured by insurance company associations with the I.S.O. Municipal Grading Schedule [Foster 1988]). Data collection on defensive actions in studies like the DSFS should, therefore, be carefully structured to reveal any actions taken to protect the structure - so that defended structures are not compared with undefended structures. The only data element on defensive actions reported by Abt et al. (1987) for the Florida Palm Coast fire was presence or absence of roof watering. One resident on the Paint fire saved his house (in part) by simply pulling up and throwing away individual wood shakes as they ignited. Care should be taken to allow for capture of such innovative protection efforts. While fire fighters are limited in their ability to stop the spread of fast moving conflagrations, actions on individual structures can be decisive. No quantitative analysis of defensive actions by fire service personnel has been reported. The present DSFS survey instrument has 13 data elements on fire service actions or capabilities. Unfortunately, data collection from the Paint fire on these factors was limited.

SUMMARY

Structures have been observed to survive wildland fire exposure even under extreme conditions such as during the Australian Ash Wednesday and Santa Barbara Paint fires. A very common reaction to such conflagrations is to maintain that little can be done to protect homes exposed to high intensity fires. The survival of some structures is often viewed as a miraculous occurrence or "dumb-luck". In fact, several Paint fire residents with undamaged homes stated that they lived through previous conflagrations and specifically designed their present homes to survive wildland fire exposure.

Furthermore, the pattern of survival does not appear to be haphazard or miraculous. Careful postfire structure loss analysis has revealed that factors such as fire intensity, vegetation clearance, roof type, and defensive actions are clearly associated with structure vulnerability to wildland fires. Better data collection is needed for both incident reporting, to characterize the magnitude of the problem, and for research, to elucidate the nature of the problem. The most useful information can be obtained from the remains of destroyed structures and those structures surviving wildland fire exposure, if survey instruments, trained personnel, and an organizational framework are in place before major incidents.

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