MODELING URBAN FIRE GROWTH

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ABSTRACT

Under FEMA Contract DCPA01-79-C-2065, IIT Research Institute (IITRI) employed existing models for debris transport and fire behavior to assess the value of existing blast/fire/people survivability data. Presentations at prior Asilomar Conferences have addressed debris transport and overviewed survivability results. The purpose of this presentation is to examine potential weaknesses of the fire spread model.

The IITRI Urban Fire Spread Model as well as others of similar vintage were constrained by computer size and running costs such that many approximations/generalizations were introduced to reduce program complexity and data storage requirements. Simplifications were introduced both in input data and in fire growth and spread calculations. Modern computational capabilities offer the means to introduce greater detail and to examine its practical significance on urban fire predictions.

Selected portions of the model are described as presently configured, and potential modifications are discussed. A single tract model is hypothesized which permits the importance of various model details to be assessed, and, other model applications are identified.

INTRODUCTION

Prediction of the fire behavior of an urban area subjected to a nuclear attack is necessary for evaluating damage, casualties, and the effectiveness of countermeasures. Indeed, fires grow and spread over an extended period of time, and this growth can be strongly modified both by preattack passive countermeasures and by human actions taken during the relatively long transattack period. Furthermore, the initiation and growth of new fires in a specific local area are affected not only by their immediate surroundings, but by fire development over a much broader area in terms of firebrands, winds, air quality and gross radiation levels, including factors from or related to mass fire development.

Even a cursory examination reveals that large numbers of parameters and processes are involved. These mandate computer assessment if any level of detail is to be preserved. Conceptually, computer modeling of urban area fires is straightforward. It involves programming the processes and inputing pertinent data parameters describing the urban area. However, the various processes interrelate and the number of structures in an urban area is quite large. Thus, the calculations become complex and extremely voluminous.

The major development of computerized urban fire spread models occurred in the late 1960s (1)(2)(3). Each employed various techniques, primarily of a statistical nature, to make calculations manageable within the available computer memories. Each benefitted from lessons learned in an earlier attempt by IITRI to produce a more deterministic model (4). This earlier model treats weapon initiation of fires from a probability point of view, considered necessary as furniture locations in rooms were assumed not to be predictable. Fire spread and other input data were treated deterministically, prescribing go or no-go conditions. Firebrands were of stated concern, but not introduced into the model; fire spread was solely by radiation.

The basic philosophy developed in the early model was to apply calculated ignition probabilities to local city areas called tracts (several blocks of relatively uniform characteristics) by Monte Carlo techniques. Spread across tract boundaries was to be assessed by similar means. The results of repeated computational exercises (computerized fire experiments) were to be used to develop analytical approximations of fire spread within tracts and across various tract boundaries. These, in turn, were to be fitted together by Monte Carlo methods to form the overall model for urban fire spread.

Unfortunately, computer capabilities in the early 1960s were such that the time required for one fire spread calculation in a tract of 100 buildings equalled or exceeded that which would occur in the real fire. Considering the number of runs required to attach statistical significance to the results for just one tract, the problem of examining an entire city becomes obvious. The solution at the time was to develop an interim model for minimum expected damage which considered fires not to spread across streets. In this simplified form, the model was employed by the National Military Command Systems Support Center to estimate fire damage and, with some assumptions, casualties. Also, it served as the starting point for Firefly (3). Potential benefits of this early model, as yet not exploited, are the detailed inter- and intra-building fire spread calculation techniques and the extensive sensitivity studies performed and reported (4).

POTENTIAL MODEL DEFICIENCIES

The more recent IITRI model (1) will be examined here. It has been modified over time to include effects of fire suppression efforts (5) and blast-suppressed ignitions (6) and to refine prediction of spread by firebrands (6). Most recently, the model was adapted for use in regions of moderate blast damage (7). None of these modifications/adaptations have changed the basic procedures for assessing primary ignitions or radiation fire spread. Potential model deficiencies in these areas are illustrated. Note in addition that the model does not presume to calculate mass fire behavior. It does, however, provide output of heat release and active fire locations with time for input to future mass fire development criteria or models.

Primary ignition calculations presently assume all buildings have one wall directly facing ground zero. This tends to maximize the interior room areas supplied with critical ignition energies in those rooms exposed to the thermal pulse; but, minimizes the number of rooms "seeing" the pulse. The assumption thus overestimates the number of rooms receiving primary ignitions of furniture (Figure 1) and underestimates the number of rooms where draperies and curtains are ignited. Since draperies and curtain ignitions appear more prone to blast-wave extinctions, it is not clear whether the net effects of the above assumption are high or low at any given building orientation and distance to ground zero.

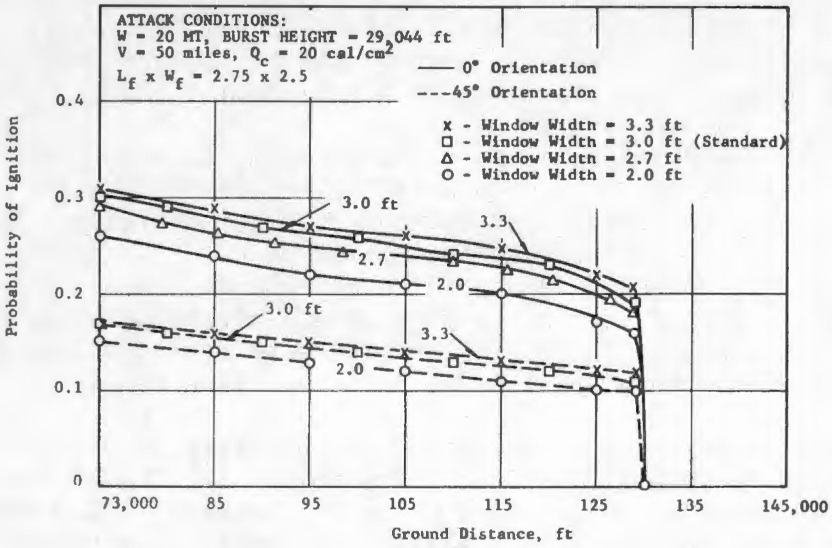

Figure 1. Probability of a chair being ignited as a function of window width, distance and orientation to ground zero. (4)

The impacts of assumptions introduced into radiation fire spread modeling are not so simply described and readily assessed. First, note that radiation fire spread depends on many factors, including separation of radiant source(s) and target, target susceptibility to ignition, presence or absence of pilots (sparks, brands, open flames), and intensity of the radiant sources. Also, the intensity of each radiant source (burning building) is a function of time, number and location(s) of ignition(s) and resistances to fire spread within the burning building; and, the radiant exposure on a single target may be the net (or total) exposure due to several radiant sources.

The present IITRI model (1) incorporates this variety of information, but the detail is lost as the model uses statistically distributed times of active burning (assumed to represent most likely times of peak radiant strength*), ignition susceptibility for target materials, and building separations (based on surveys of "typical" actual areas). Indeed, the model has been criticized by Schmidt (8) for arbitrarily increasing all building separations in relation to the number of "burned out" buildings with time. Unfortunately, the true impact of this latter assumption is still not known; the analysis presented by Schmidt retains many other, related assumptions of the IITRI model.

While concerns such as these raise some question about the adequacy of model-predicted ultimate fire damage, of comparable importance is the fact that the present IITRI model (and its contemporaries) does not permit detailed time-based, building-by-building analysis of local fire development and spread. This somewhat limits the confidence placed on model-based measures of the effectiveness of suppression activities, and places strong constraints on use

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* The same technique, but a different time distribution, is applied to firebrand generation.

of the model to characterize the fire vulnerability of specific local areas of interest such as key industries or regions immediate to key worker shelters. The figures (4) illustrate details of fire development and spread lost in the statistical nature of the models in current use.

The building employed for the following examples is a three-story multi-family apartment, the typical Chicago six-flat with two apartments per story sharing a common front entry and stairwell, with somewhat independent rear entries. Rear doors open to independent rear porches which share a common open rear stairwell. Figures 2 and 3 illustrate the effects of different numbers and locations of ignitions on the subsequent history of fire development within the building (time from ignition to significant involvement of the ignited compartment, and fire resistance of interior barriers, fixed for these examples).

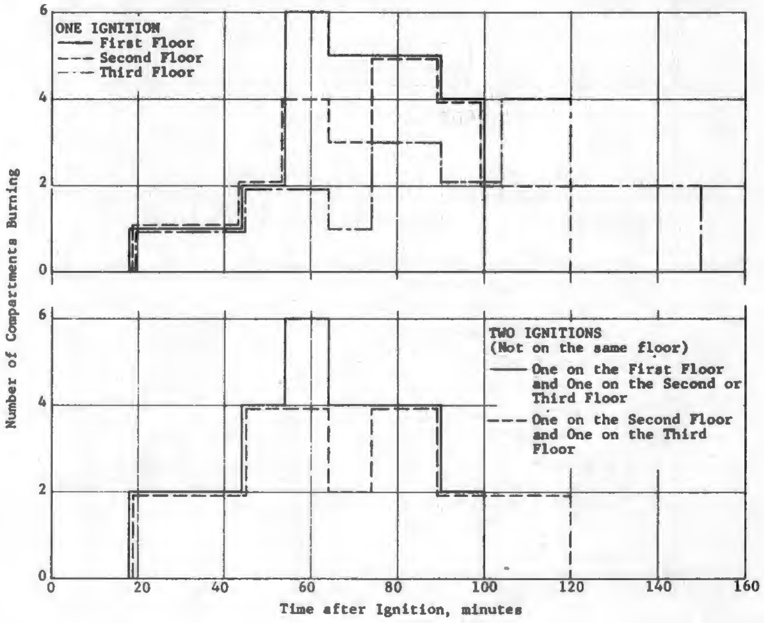

Figure 2. Effect of location of one or two ignitions on compartment burning in "six-flat". (4)

The strength of the radiant source formed by a burning building is a function of which compartments are burning and whether or not internal ceiling-floor constructions or ceiling-roof constructions are still intact. Drawing on experimental results generated in a supporting effort (9), examples of radiation intensities on a target 20 ft from the building are illustrated in Figure 4. In all of the stated examples, fire spread throughout each apartment was considered to be relatively unhindered (open doors) with major delays (closed doors, other barriers) to spread between apartments. This can be generally considered to be the case; thus, the assumptions of the current model (1) in this regard have some affect on results for single family residences, but much greater impact on results for apartments, condominiums, and hotels.

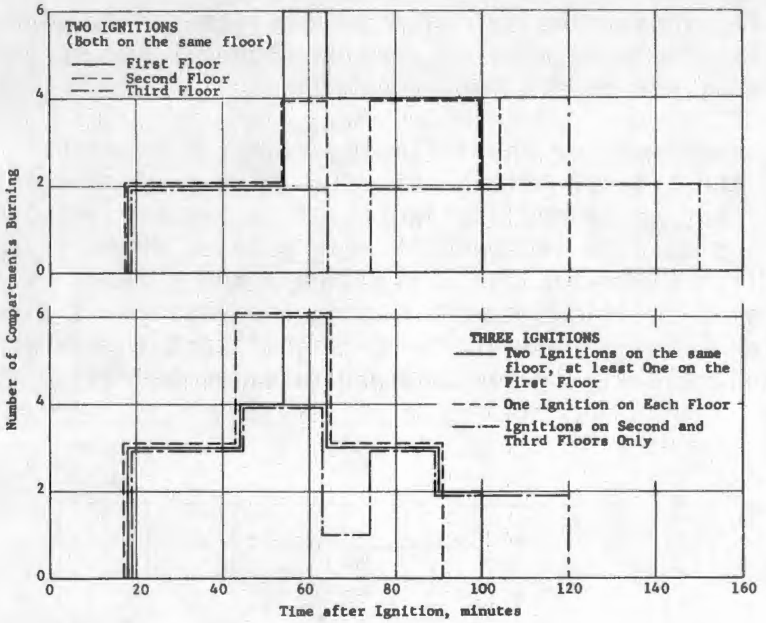

Figure 3. Effect of location of two or three ignitions on compartment burning in "six-flat". (4)

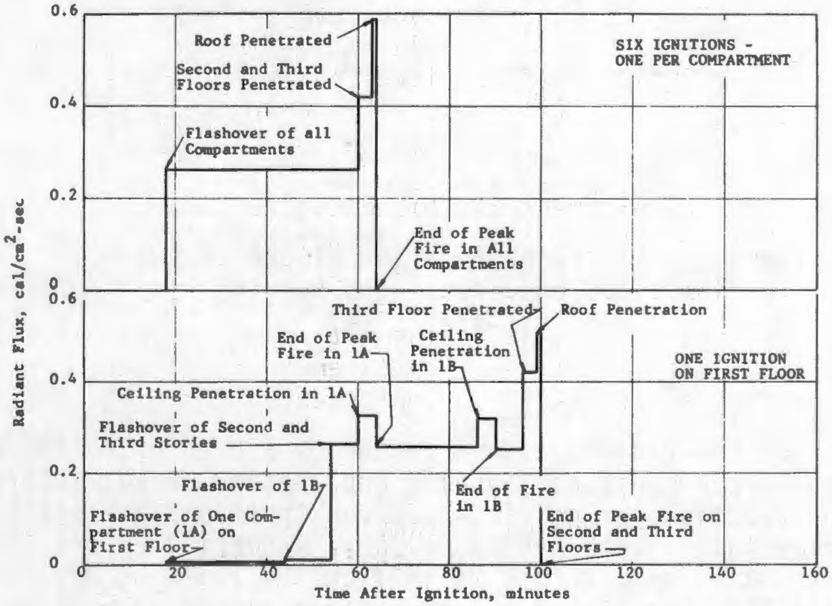

Figure 4. Calculated Radiation from the Front of a six-flat for two ignition patterns. (4)

Not all model weaknesses are computer related. We still have many uncertainties related to our basic knowledge of the phenomena. Among the many inadequacies are: (1) affect of residual heat from the weapon pulse on fire growth to room flashover; (2) affect of exposure fires on fire growth in ignited room or building; (3) detailed characterization of firebrand escape from fire plume, trajectory near target; and (4) local wind variation.

RECOMMENDED MODEL DEVELOPMENT

A new model should be constructed taking advantage of the speed and storage capacity of modern computational facilities. The model should address, at first, a localized urban area similar to the previously used "tract". By initially considering a local area instead of an entire city, the model can incorporate greater detail than may be practical for the entire city as a whole, even with modern computers.

The model should be constructed, to the degree possible, in a deterministic manner, modularly designed for ready modification of selected input or calculation processes as these are deemed inadequate by state of the art information or weaknesses identified by exercising the model. On a local area basis, the model lends itself particularly to parameter sensitivity analysis to define the importance of the various levels of detail included, and to examine the need of further refinement, where data or "physics" are lacking. At this level of development, the model also can be used to examine fire spread through areas of various structural types, structural mixes, building density, and damage levels to provide a "Fire Vulnerability Index" for local assessment of fire danger levels, perhaps comparable to the blast "vulnerability numbers" presently in use.

At this level of development, the model can assess the effects of wind, humidity and precipitation on local fire growth. Through certain assumptions regarding the upwind boundary, a first level of "conflagration potential" can be addressed. At the very least, levels of wind and heating required to significantly affect downwind fire spread can be identified.

Upon satisfactory development of this detailed local area model, it could be applied to the entire city in a manner compatible with its complexity and utility. In its simplest use, it could be applied to selected local areas under the influence of a general urban fire described by the present urban fire models (1)(2)(3), or with some refinement suggested as critical by the above-mentioned sensitivity analyses. In essence, it could be introduced into blast-fire analyses such as those performed by IITRI under work unit 2564D (7).

Should size and complexity of this new "local area" model permit, it could completely replace the present "tract" model and be used to describe all tracts in the entire urban fire area in detail, or at selected levels of detail.

To complete all aspects of model development and application will require a significant expenditure of time and effort. It appears reasonable to target the "local area" model development and some measure of sensitivity analysis as the first goals. Armed with the information and insight so obtained, the remaining course of action and ultimate goals may be refined and defined more precisely.

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