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The Relationships Between Fire Service Response Time and Fire Outcomes

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Abstract. Fire service response to fire is premised on the assumption that the earlier the fire is attacked the smaller will be the consequences to people and property. A simple method is shown for measuring the influence fire service response has on building fire development. The results for New Zealand are shown. The method is then extended to determining a nominal monetary benefit from rapid response and benefits in terms of other desired outcomes. The method allows the benefits of monitored fire alarms and sprinklers to be quantified. Finally the method is extended to determining the impact on fire service response of calls from cellular phones versus standard landlines. In the New Zealand circumstances the use of cellular phones does not appear on average to provide a speedier alert to the fire service and generally involves a marginally slower response owing to delays in locating incidents. This results in a measurably greater monetary loss.

Keywords: Economic value of rapid response, Fire condition on arrival, Monetary loss to fire

1. Introduction

Fire service emergency response to fire is on the basis that the earlier the fire is attacked the smaller will be the consequences to people and property. This investigation considers the statistical relationship between fire service response and the outcome of the fire. While the analysis is specific to the New Zealand situation it is expected that the methodology may be applicable in other jurisdictions which collect similar information. The analysis is applicable to fire service management rather than the modelling of fire development.

Considering the popular image of emergency response to fire in buildings there is very little research into the actual utility of quick response by fire services. Särdqvist and Holmstedt [1] found little support for the hypothesis that short arrival times result in smaller fires. Holborn et al. [2] consider fire development from the moment of ignition and within the theoretical framework of fire growth with fire service response being a small component only. Cortez [3] focuses on post-arrival fire management but acknowledges that even with longer response times the flashover incident rate is relatively low.

This research uses data for approximately 27,500 fires in structures throughout New Zealand attended by the New Zealand Fire Service [4] over the period from July 2003 to June 2008. This constitutes the entire population of fires in

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New Zealand over the period which involved an emergency call to the fire service. The New Zealand Fire Service has sole responsibility for emergency response to building fires in New Zealand. The distribution of fires used in each part of this analysis is shown in the appendix. The New Zealand housing stock is predominantly made up of bungalows of timber frame construction.

2. Method

New Zealand experiences about five and a half thousand building fires each year. The New Zealand Fire Service routinely collects data on the apparent state of the fire at the time of arrival of the first pump capable fire appliance. The information is mandatory for all structure fires and consists of one of the following options:

- Out on arrival
- No fire or smoke
- Smoke only
- Small fire
- Large fire
- Totally involved fire
- Not known

The distribution of fires across these categories is shown in Figure 1. Less than 0.1% of structure fires have 'Not Known' recorded in this field. 19% of structure fires are described as being large or fully involved at the time of arrival. There is no set definition for these states and interpretation as to meaning is up to

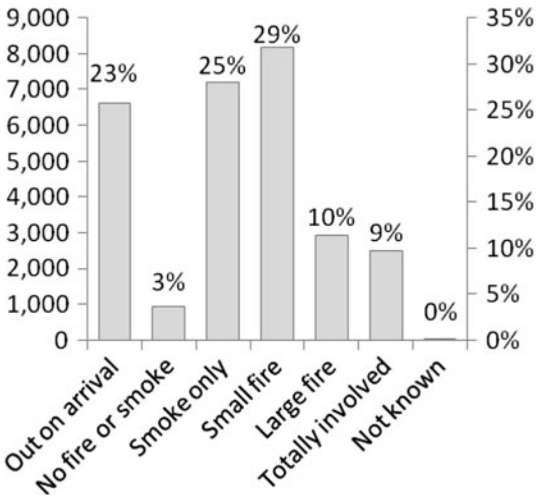


Figure 1. Distribution of fires across categories of the state of the fire at arrival of the first fire appliance [*n* = 27455].

individuals completing incident reports. However, Figure 2 indicates that a fire which is described as large typically results in flame damage to the structure in excess of 30 m^2.

All structure fires were classified according to the response time of the first arriving pump capable fire appliance and the proportion of these which was described as either 'large fire' or 'totally involved fire' was identified. The time considered is the duration from the time of the initial receipt of the emergency call to the time that the first appliance arrives. The circumstances prior to the raising of the alarm are not considered. Neither is the time to set up and start attacking the fire considered. One minute categories were found to be adequate.

Good response time data is available throughout the period with time-stamping by the electronic dispatch system based on radio transmitted codes. All structure fires with and without damage to the structure were included in the analysis, on the basis that all fires have the potential to develop into large fires if not controlled. Fires in chimneys were not included as they pose no major risk to the structure. In the New Zealand context fire service response starts automatically at the moment an emergency call signal arrives at the fire service communication centre and includes time to answer the call, verify the location of the incident, dispatch fire appliances, crew congregation and time to travel to the incident location.

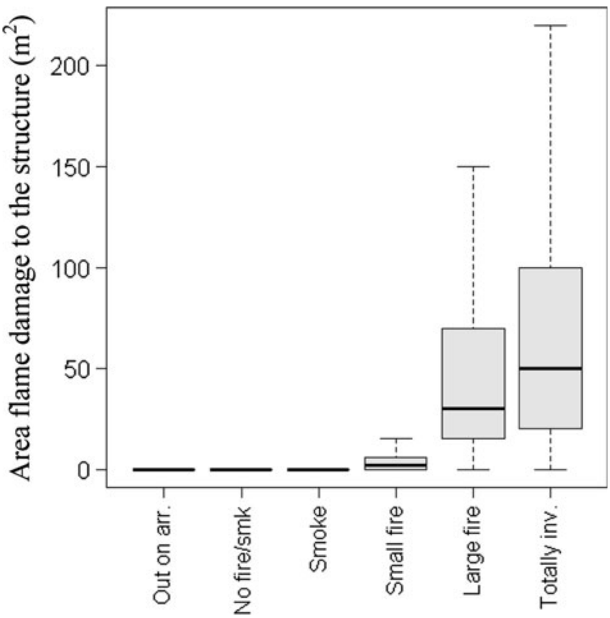


Figure 2. Box plot of the area of damage resulting from the fire for each reported state on arrival of the first fire appliance. The *heavy line* is the median, the *box* shows the range which encloses 50% of the values and the whiskers show the 90% range [*n* = 27455].

3. Result

Figure 3 shows the result for all structure fires with a response time under 30 min. The increasing variability beyond approximately a 20 min response is noise and reflects the very small number of incidents involving responses in this range. Similarly, there is each year a small number of incidents (approximately 5 per year) where the total response time is less than 1 min. These tend to be occasions where the fire was first detected by a passing fire appliance. They are aberrant and not included in this analysis.

The optimum fit to this distribution is a power function $y = 0.06x^{0.6602}$ ($R^2 = 0.95$). The area of primary concern from the fire service management viewpoint is the first 15 min which involves 95% of all responses. Very slow responses are generally caused by factors beyond the control of the fire service. The analysis here focuses on the first 15 min and uses a linear fit ($y = 0.023x + 0.043$). This achieves a closer fit over the range of interest ($R^2 = 0.97$). By using a linear regression to approximate a power function this analysis becomes sensitive to the chosen response time constraint.

The chart shows that the relationship between response time and fire size across a *statistical population* of building fires is approximately linear. It is not representative of the relationship between response time and fire growth for any individual fire. The conditions relating to any individual fire are unique and the position of the fire within the population of fires is not known.

3.1. Confidence Analysis

Figure 4 shows the twice standard error bands for each minute based on data for the 5 years from 1 July 2003 to 30 June 2008. The intervals are greatest for minutes one and greater than 12 min, where the number of applicable responses is much lower, as shown by the density function.

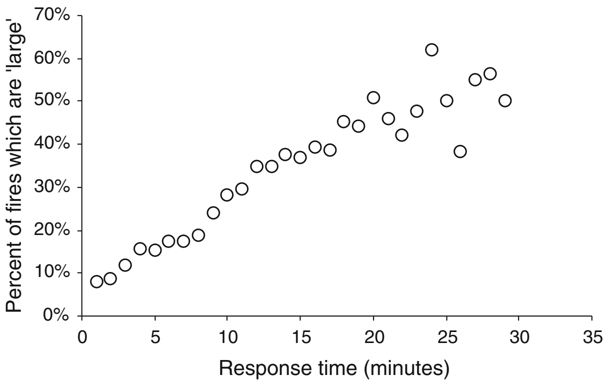


Figure 3. The proportion of building fires in each response time category which are described as either a large or fully involved fire at the time of arrival of the first fire appliance [n = 27455].

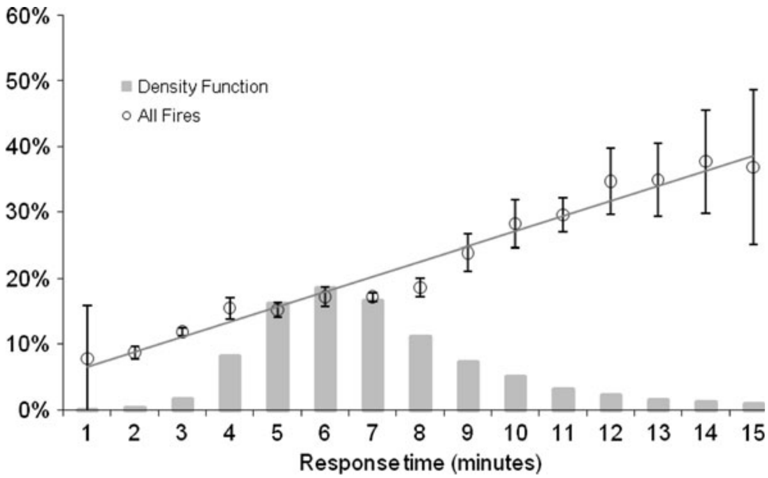


Figure 4. The proportion of fires in each minute category which are large at the time of arrival showing the twice standard error bands and the density function for all responses to fire. The *vertical* scale is the same for both series. For the density function it is the percentage of the population [*n* = 26384].

3.2. Fires Which are Large at the Time of Emergency Call

A response time of zero coincides with the initiation of the emergency call. An extrapolation of the linear fit to call initiation at zero response time indicates that approximately 4% of structure fires are large at the time the call is placed.

3.3. Fire Growth

The slope of the linear trend line indicates that for every 1 min increment in response time (x), the proportion of fires described as large on arrival (y) will go up by 0.023, or 2.3%.

4. Further Analysis

The same method was applied to other available information for New Zealand structure fires.

4.1. Structural Value Lost

The New Zealand Fire Service uses commercially available quantity survey per-square-metre-cost-of-construction data [5] in order to calculate a nominal dollar value of structural loss for every building fire. The value is derived from an estimate of the area of flame damage to the structural fabric of the building.[1] For

[1]The calculation uses fire fighter estimates of the square metre damage from flame and the fire fighter attribution of building use. The estimates of damage are highly error prone but can be used statistically.

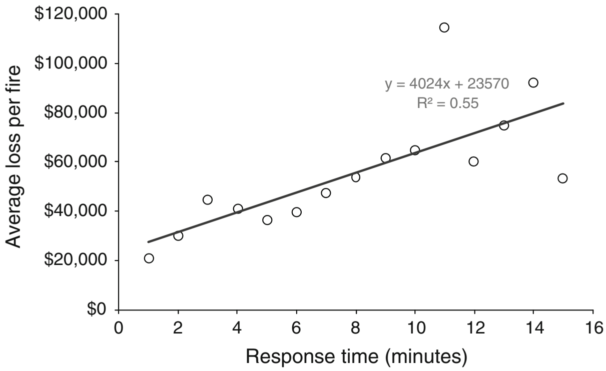


Figure 5. The nominal average value ($NZ) of damage to the structure per fire for each minute of fire service response [*n* = 26384].

residential buildings (65% of fires), this is adjusted in accordance with the findings of Page [6] in order to arrive at a more accurate estimate of actual repair cost. The accuracy of the estimate for non-residential properties is not known.

Figure 5 shows that the cost of damage increases with response time at the rate of approximately NZ$4,000 per minute per fire.[2] This relationship has great potential for determining the benefit/cost ratio from improved response.

These values bear no direct relationship to the estimated costs of building fires in New Zealand made by Goodchild et al. [7] which are based on insurance claims. Goodchild's estimated annual value of building *and contents* lost to fire is NZ$129 million. The New Zealand Fire Service estimates based on quantity survey figures used here equate to approximately NZ$145 million for damage to the building only. Both methods for estimating costs involve significant assumptions but the separate attempt by Page to validate the New Zealand Fire Service method for residential buildings suggests that Goodchild's estimate may be a bit low.

4.2. The 4 min to 8 min Plateau

The figures above show a distinctive plateau between approximately 4 min and 8 min response times. This is the area of highest sample confidence. It coincides with the peak in the density distribution and includes 70% of all responses. Over this range the rate of increase in the proportion of large fires falls to 0.008 (or 0.8%) per minute. Figure 6 shows the density of small fires[3] and large fires. The respective kurtosis suggest that the spread from the mean is greater for large fires than for small fires and this would have the affect of reducing the proportion of large fires around the peak in the distribution.

The implication of this is that for the majority (70%) of fires where the response is within 4 min to 8 min, a slightly speedier response will on average

[2] Approximate exchange rate is NZ$1.00 = US$0.60.

[3] An aggregation of out on arrival', 'no fire or smoke', smoke only' and small fire'.

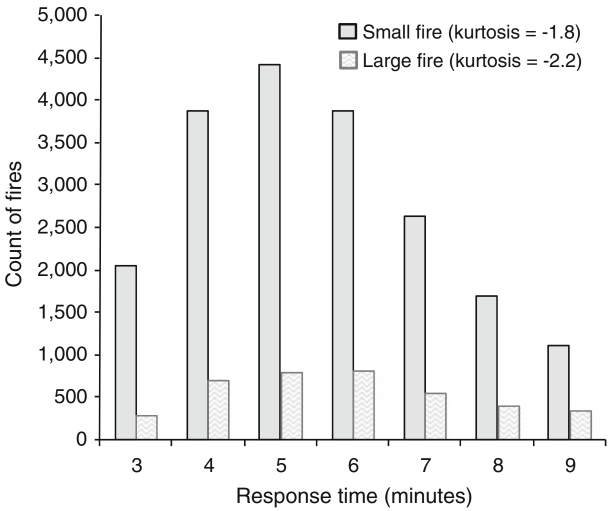


Figure 6. The density of small and large fires over the response time range with the measure of skewness [*n* = 22976].

make only marginal difference (0.8% per minute) to the resulting structural damage. The difference may however be considerable for any particular fire.

4.3. Moderate and Life Threatening Injuries in Fire

Figure 7 shows the relationship between response time and the percentage of structure fires which involve moderate or life threatening injuries. An apparent negative relationship might seem surprising but a closer look suggests that the relationship is complex. Over the 4 min to 7 min range which includes 63% of incidents and 69% of casualties, the relationship is positive, suggesting that a prompt response does result in fewer casualties in most circumstances.

A comprehensive investigation of this relationship is beyond the scope of this paper. 90% of these casualties occurred in a residential setting and some possible explanations include:

- A behavioural explanation would be for smaller fires to be more likely to trigger a ‘fight’ response to the duress of fire, while larger fires trigger a ‘flight’ response. The prevalence of smaller fires for early fire service response times might therefore result in a higher rate of casualties as a result of attempts to fight the fire.
- The relationship between response time and fire injuries may not be direct. Fire stations tend to be located close to socio-economically deprived town centre housing. A number of studies have identified a relationship between socio-economic status and fire related injuries [8]. It might therefore be expected that areas of low socio-economic status will experience prompt fire service response and will have relatively high casualty rates compared to the wealthier and more remote suburbia.

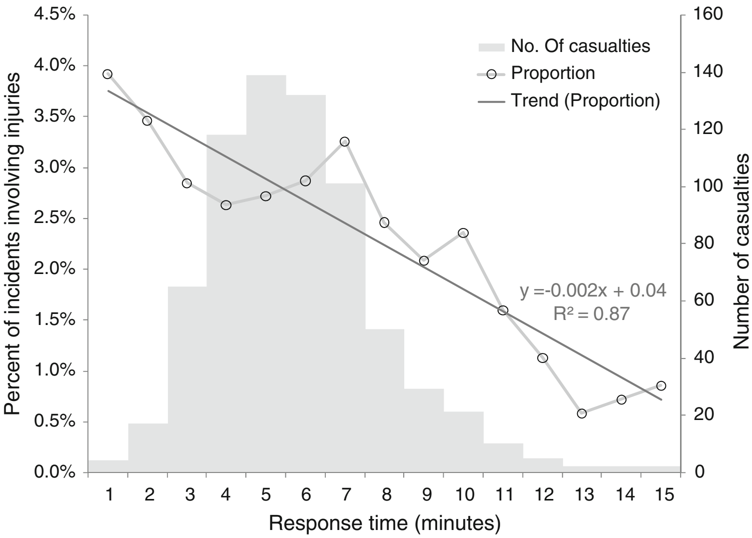


Figure 7. The proportion of fire incidents involving serious injuries to members of the public for each minute of fire service response. The response time data are discrete sets and the lines linking the data values is for highlighting purposes only. The *grey bars* and the *right* scale show the distribution of casualties [*n* = 699 injuries].

4.4. Fatalities from Structure Fire

There is no discernible relationship between fire service response time and the occurrence of fire fatalities (102 fatalities, $r^2 \approx 0$). This would confirm the belief general within fire services that occupants need to self-evacuate long before the fire service arrives.

4.5. Response to Monitored Fire Alarms

The initial analysis was for all structure fires regardless of the source of the call. In the New Zealand circumstance, all commercial buildings with sprinkler systems must include detection systems connected directly to a fire service communications centre, and many buildings with only smoke/heat detection systems are connected also. It might be expected that responses to alarm activations from monitored automatic private fire alarms (PFAs) would be much faster than those originating from callers using the emergency telephone number (111 in New Zealand). Alarm activations will normally be early in the fire development, are notified directly to the fire service communications centre,[4] the location is immediately known and the emergency response is pre-planned. Figure 8a shows the percentage of fires which are described as large or fully involved on arrival for emergency calls

[4]New Zealand is covered by three communications centres operating seamlessly as a single system.

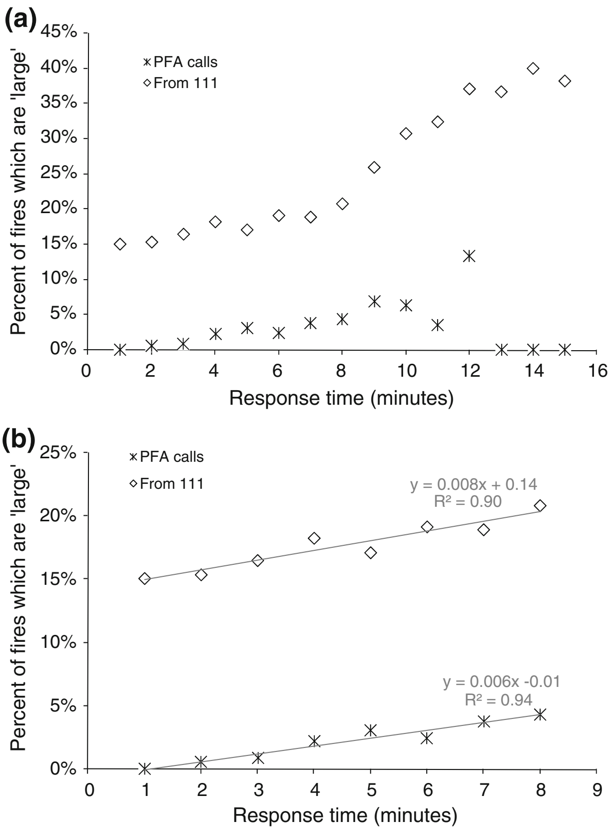


Figure 8. The proportion of fires which are large at the time of arrival for alarms sourced from PFAs and 111 emergency calls a for response time range from 1 min to 25 min [from 111 *n* = 23976, from PFA *n* = 2408], b for response time range 1 min to 8 min only [from 111 *n* = 18406 (77%), from PFA *n* = 2244 (93%)].

originating from PFAs (with sprinklers and/or detection) and from 111 calls. The analysis excludes the 96% of alarm activations which are false alarms.

Both series show a distinct threshold at 8 min response time. The rate of large fires for calls originating from 111 increases markedly beyond 8 min, while the rate for calls from PFAs becomes unstable beyond 8 min. Figure 8b shows a linear fit for the 1 min to 8 min range which includes 77% of 111 calls and 93% of PFA calls.

The equations for the linear fit show that no fires are large at the time of receipt of a PFA alert compared to 14% for 111 calls. The proportion of fires which are large increases at approximately the same rate of 0.7% for each extra minute of response for both call sources until 8 min. Beyond 8 min the proportion of large fires for 111 calls starts increasing at a rate of over 2% for every extra minute of response time.

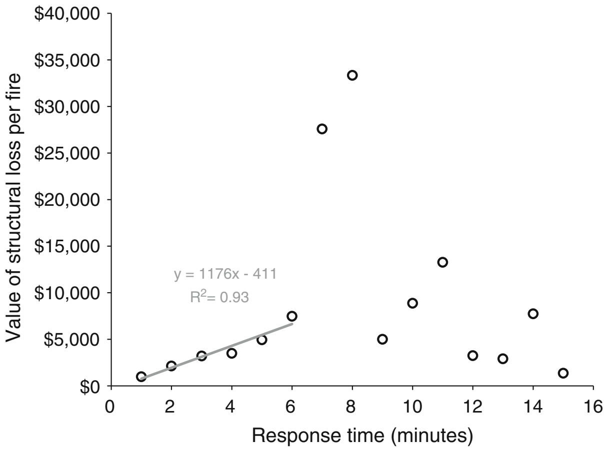


Figure 9. The nominal average value ($NZ) of damage to the structure per fire for each minute of fire service response for alarm monitored buildings only.

Note that there are no large fires in buildings with monitored alarms with a response of longer than 12 min. This reflects the fact than most buildings with monitored alarms are commercial buildings in metropolitan areas covered by full-time fire fighters. Consequently they receive a faster response.

Figure 9 shows the average value of loss per fire for each minute of response time for alarm monitored buildings. The data becomes unstable beyond a 6 min response owing to small numbers of fires in this range (14%, 407 fires, are beyond 6 min). In the stable timeframe up to 6 min damage increases at the rate of NZ$1,176 per minute of response, approximately a third of the overall rate for all fires.

4.6. Response to Sprinklered Buildings

Buildings with sprinkler systems are a subset of the monitored fire alarms in the previous section. The population of fires in sprinklered buildings during the 5 years under consideration here is small, only 284. Of these, ten were considered to be large fires at the time of arrival of the first fire appliance. There is no discernible correlation between the cost of damage and the response time of fire services. There is no evidence of any economic benefit from having a large and rapid response to alarms in sprinklered buildings.

4.7. Responses to Cellular Phone Calls and Landline Calls

Previous analysis by the author of fire emergency service dispatch data for recent years indicates that emergency calls from cellular phones consistently take on average 15 s longer to locate the incident than for calls from landlines where there is always a known terminating address for the telephone line.[5] Figure 10 shows that

[5]For this analysis landlines excludes alarms from monitored private fire alarms as the location is always immediately known for these.

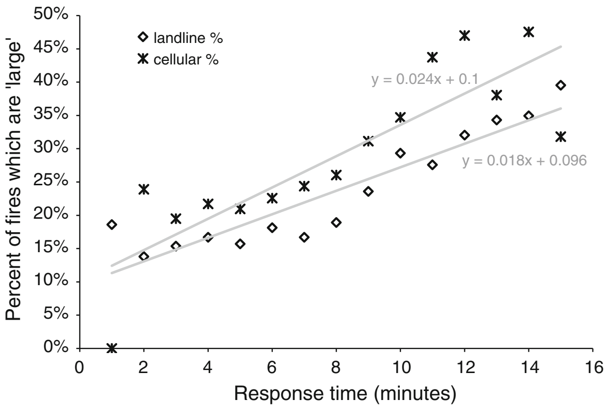


Figure 10. The proportion of building fires which are described as either a large or fully involved fire at the time of arrival of the first fire appliance for calls from cellular phones and from landlines [landline *n* = 17038, cellular *n* = 5066].

this difference results in a small but persistent difference in the proportion of large fires at time of arrival of the fire service. The respective regression equations indicate that about 10% of fires are large at the time of call initiation (at response time = 0) for both cellular calls and landline calls, which would suggest that on average the more immediate availability of cellular phones provides no advantage over landlines.

The structural value loss analysis above indicates that damage increases at the rate of NZ$4,024 per fire for each minute of delay in response, or NZ$671 for each 10 s. There is on average 1,013 structure fires per year where the emergency call originates from a cellular phone. Therefore the annual fire damage attributable to the delay in incident location is approximately $1 million (NZ$671 * 1.5 * 1,013).

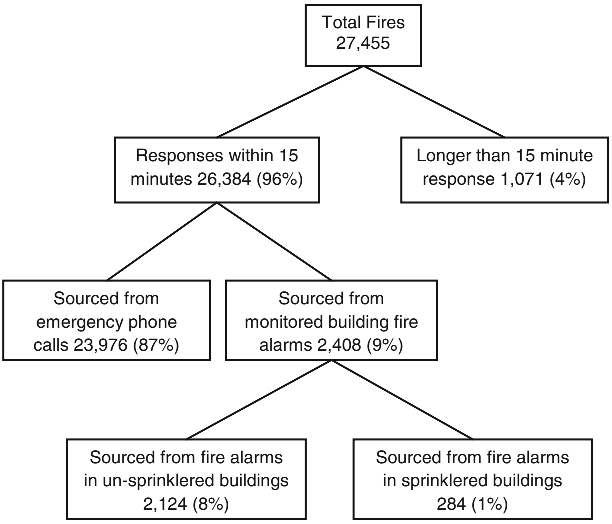
5. Conclusions

Response time of fire services has a clear correlation with the amount of structural damage. Regression analysis indicates that only about 4% of New Zealand building fires are of significant size at the time the emergency call is placed. This percentage rises to about 14% when manual emergency calls are considered and falls to zero for automatic fire alarms. In general the cost of structural damage increases at the rate of approximately NZ$4 thousand per fire per minute of response time. Monitored fire detection systems reduce the damage by two-thirds when there is a quick fire service response. Significant fires in sprinklered buildings are too few to be able to identify any measurable benefit from a rapid fire service response. While there is no evidence that cellular phones enable earlier reporting of fires, they do cause a delay in locating the incident.

Surprisingly, serious injuries are inversely correlated with fire service response times, but this may indicate an indirect relationship. The number of fire fatalities shows no relationship to response times.

Appendix

The proportion of the data set of all building fires used at each stage of this analysis



References

1. Särdqvist S, Holmstedt G (2000) Correlation between firefighting operation and fire area: analysis and statistics. Fire Technol 36(2):109–129
2. Holborn PG, Nolan PF, Golt J (2004) An analysis of fire sizes, fire growth rates and times between events using data from fire investigations. Fire Safety Journal 39:481–524
3. Cortez Lawrence (2001) Fire company staffing requirements: an analytic approach. Fire Technol 37:199–218
4. New Zealand Fire Service, Station management system incident data 2003–2008
5. Rawlinsons Handbook (2005) see http://www.rawlinsons.co.nz
6. Page I (2009) The cost of repair to fire damaged buildings. NZFSC Report no 91. New Zealand Fire Service Commission, Wellington
7. Goodchild M, Sanderson K, Leung-Wai J, Nana G (2005) The cost of managing the risk of fire in New Zealand, *NZFSC Report Number* ***53***. New Zealand Fire Service Commission, Wellington
8. Miller I (2005) Human behaviour contributing to unintentional residential fire deaths 1997–2003. NZFSC Report no 47. New Zealand Fire Service Commission, Wellington