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Temporal and spatial patterns of fire incident response time: a case study of residential fires in Brisbane

Abstract

Prompt and timely response to fire incidents is critical for emergency management as delays in the departure and arrival at the scene can have significant consequences in terms of death, injury and damage. Research on response times has received limited attention due to restrictions in data access. This paper addresses this gap through investigating the spatial and temporal dynamics of residential fire incident response times in the Brisbane Statistical Division (BSD), Australia. Incident data supplied by the Queensland Fire and Emergency Service (QFES) for the period of 1998 to 2013 is analysed using a spatial analytic approach. Results show differences in response times across specific periods of the day, week and in particular seasons, and that the degree of this variation may reflect variations in the demand for service. Furthermore results show that response times also vary by space, however the degree of this variation are shown to be positively associated with population densities, i.e., locales with higher population densities experience faster response times, in particular the inner urban parts of the study area. We conclude through emphasising the importance of these results in their capacity to contribute to a new evidence base to inform policy decisions from a resource allocation perspective through the spatial and temporal allocation of finite resources.

Keywords: *Residential fire, response time, temporal dynamics, spatial dynamics.*

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1. Introduction

Fire causes significant impact to people in terms of economic, social, physiological and physical damage (Corcoran et al. 2009). Structural fires, and in particular, residential fires continue to significantly affect people's lives and properties (Ceyhan et al. 2013). In Australia, each year residential fires cause 100 fatalities, 3,000 injuries and billions of dollars associated with property loss (Productivity Commission 2007).

Prompt and timely response to calls for emergency service is critical as delays in the departure and arrival at the scene can have significant consequences in terms of death, injury and damage (Schilling et al. 1980; Li et al. 2011). Given this imperative, many countries impose service delivery standards i.e., that specify the targets in terms of the time to respond to a call for emergency service (Chevalier et al. 2012). Further, the location of fire stations is crucial in maintaining these service delivery standards so that the impacts of fire on people's lives and properties can be minimised. Determining these service delivery standards is ultimately a compromise that on the one hand attempts to minimise the risk to people and property (Murray 2013) whilst on the other minimises the public cost of fire cover (Li et al. 2011; Aleisa & Savsar 2013).

Previous research on response times have tended to focus on examining the performance of fire services, especially through linking the effects of slower responses to calls for emergency service. For example, Sardqvist & Holmstedt (2000) found little support for the hypothesis that of the faster the arrival of fire services at an incident result in smaller fires (i.e., the total area of the property that burned in a given incident). However, a more recent study by Challands (2010) found that response to calls for emergency service indeed had a positive correlation with the amount of structural damage. They employed a relatively simple method (i.e. they classified all structure fires according to response time of the first arriving fire engine and the proportion of these which was described as either a 'large fire' or 'totally involved fire') for measuring the influence fire service response imposed on to the final property damage caused by the fire. They estimated that the cost of structural damage increases at the rate of US $3 thousand per fire per minute of response time. These findings

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point strongly to the critical need for rapid response to calls for emergency service given that delays in response can have significant consequences (Tamat et al. 2014). Furthermore, Castillo (2002) stated that "there is little doubt that the more rapidly well-equipped, highly trained people reach the scene of an emergency and began to mitigate the said emergency, the better the likelihood of a positive outcome will be" (p. 25). Recently, one study by Tamat et al. (2014) examined the temporal patterns of response times in the Penang State of Malaysia identified significant differences in fire brigade's response times across months and year, and related such differences due to inadequate fire-fighting resources, traffic jam and the location of the incident (Sufianto & Green 2012; Productivity Commission 2015). They also highlighted the importance of fire station location and concluded from their investigations that "the station that services more cases but is unable to response in due time, delay in its response time, will causes greater danger because properties and lives cannot be saved during critical time" (p. 207).

However, little is still known about how the demand for fire services varies across time and space in conjunction with changes in the underlying population. In addition, there has been no research to date that has examined the spatio-temporal patterns of residential fires response times, which serves as a fundamental component for informing fire service policy and planning.

To help fill the research gap in the extant literature, this paper investigates the spatial and temporal dynamics of residential fire incident response times and their relationship with fire incidents, and links these findings to the underlying population. To this end we address two research questions:

1. *What are the temporal dynamics of residential fire incidents response times?*
2. *What are the spatial dynamics of residential fire incidents response times*?

The remainder of the paper is structured as follows: The next section presents the study area, data and the methods adopted to conduct spatio-temporal dynamics of residential fire incidents response times. The subsequent section presents the results. Finally, this paper

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concludes with a brief summary of the key findings from the analyses presented along with recommendations on potential directions for future research in this area.

2. Study Area, Data and Methods

2.1. Study Area

Brisbane Statistical Division (BSD) in Queensland State of Australia forms the focus of this study. BSD (Figure 1) comprises five Local Government Areas (LGAs): Brisbane City (the state capital and the third most populous city in Australia), Ipswich City (the oldest provincial city and major industrial centre), Logan City (residential and industrial), Redland City (home to native species and heritage sites) and Moreton Bay (state's third largest LGA and an amalgamation of City of Redcliffe and the shires of Pine Rivers and Caboolture) (ABS 2013). BSD's total resident population was recorded to be 2.08 million by the 2011 census (equating to approximately 46% of the State's population of 4.48 million), which has experienced a growth of 12.53% over the period of 6 years (ABS, 2013-2014), with in-migration being a major driver of growth (Chhetri et al 2009). Covering a total of 5,950 square kilometres area, the BSD continues to experience rapid physical redevelopment, growth, and population expansion (Hutson et al. 2008). Due to population growth, particularly in the outer suburbs and around peri-urban areas in BSD, the needs and cost for managing fires is also growing (Chhetri et al. 2009). One of the main problems faced by urban planners is to effectively manage emergency fire service calls (Tamat et al. 2014). To strategically plan for future fire stations locations, it is crucial to first capture the dynamics of fires. Specifically, through mapping the geographical variability of response times and identifying areas associated with slower response times linking the underlying population, offers evidence from which planners are able to strategically plan for new emergency resources – such as new fire stations.

2.2. Data

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A residential fire is defined as a type of structural fire occurring in a residential building (AFAC-AIRS 2004). Residential fire incident data for a 16 year period (1st January 1998 to 31st December 2013) are supplied by the QFES and contain the date, time and incident location (latitude and longitude) along with the date, time and location (latitude and longitude) from which fire resources were dispatched to the call-out for each residential fire incident data within the BSD.. The total number of residential fire incidents was 12,203 each of which included information on the response time (minutes) and responding fire stations. Additionally, residential fire incident data also provides information on attributes indicating number of fatalities, injuries and property damage.

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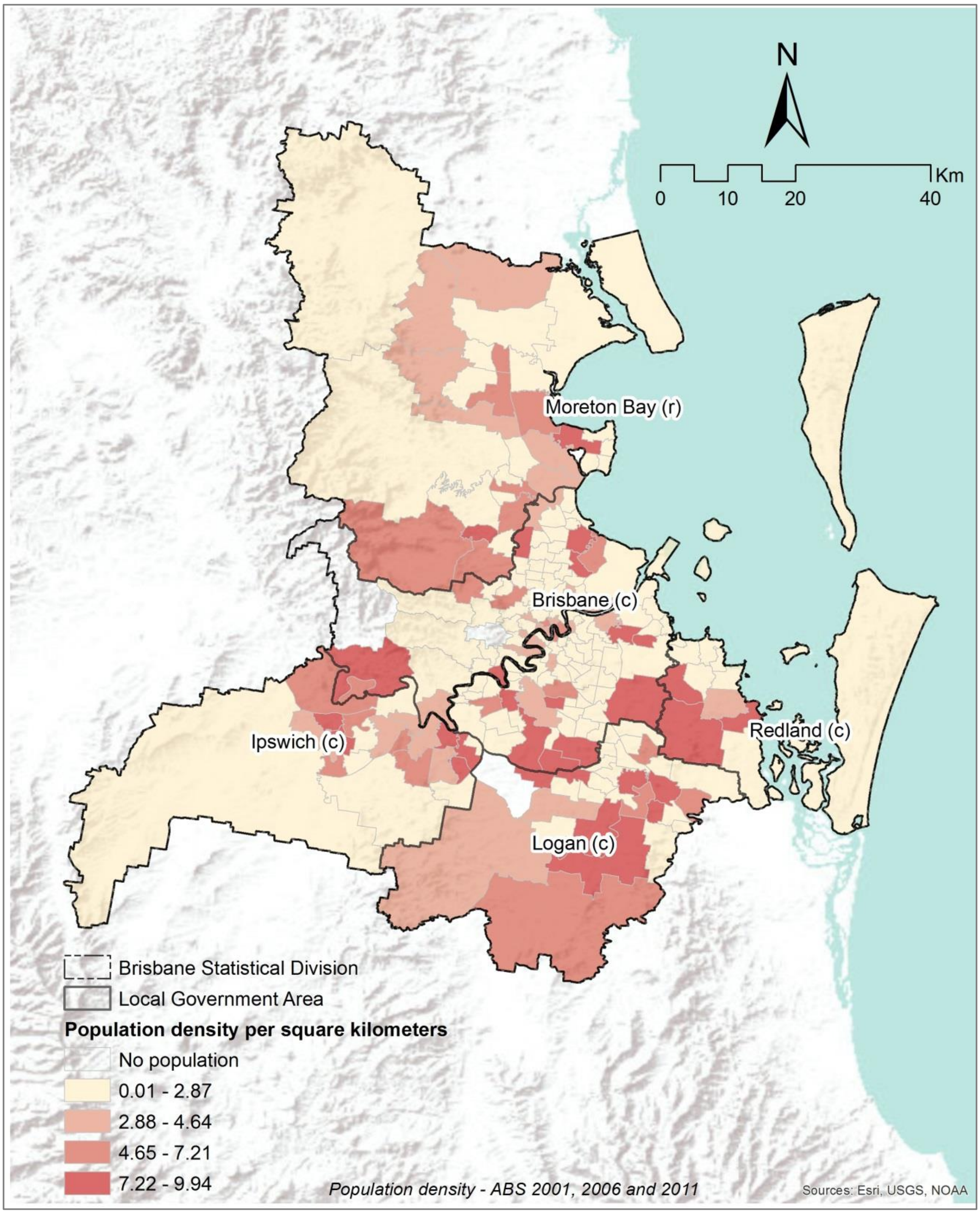

Figure 1. Brisbane Statistical Division (BSD) and population distribution

2.3. Methods

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The methodological approach comprises two main components: the first examines the temporal dynamics of residential fire incidents response times. Plotting the median and 90th percentile response times for months, days and hours response to calls for emergency service are examined against residential fire counts under these temporal granularities. Specifically, the 90th percentile response time values were used to relate the findings against the service delivery standards set by the Australian Government (i.e. 90% coverage in 12 minutes response time (i.e., travel time)) (Productivity Commission 2015). A Pearson correlation test was used to examine the relationship between response times and number of fire incidents for each temporal granularity. Similarly, a one-way ANOVA technique is used to examine the strength of the response times patterns observed under each temporal granularity. The second component examines the spatial dynamics of residential fire incidents response times. However, unlike temporal analysis, the spatial analysis mapped the 90th percentile response times and linking this analysis it to population density over 16 years describing the total population for SA2s to explain response time patterns. The resulting outputs from these analyses permitted a way through which to examine the spatio-temporal patterns of residential fire incidents response times. The detailed investigations contribute to advance our understanding of the temporal and geographic patterns of response related to calls for emergency service, provides useful insights to fire service management, that is, it establishes foundation for fire prevention and response activity and can reveal new trends (Asgary et al. 2010).

3. Results

Drawing on the 16 years of residential fire incident data, this section commences by first exploring the temporal dynamics of residential fire incidents response times in the BSD. It includes examining the key temporal patterns or response times over different temporal granularities and linking it to fire incidents to explain such patterns. Building the temporal analyses, spatial analyses are conducted to identify the geographic patterns of residential fire incidents response times and linking population density to explain such dynamics.

3.1. Temporal Dynamics

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Figure 2 illustrates 16 years of residential fire incidents and patterns response time by month. Results show that residential fires are relatively more frequent during the winter and less common in summer, a pattern also echoed by their associated response times. Correlation tests suggest a significant positive relationship between response times and incident volume by month (Spearman's rho = 0.7018 and p > |t| = 0.0110). The result shows that during winter when demands for service are more frequent, response times are longer.

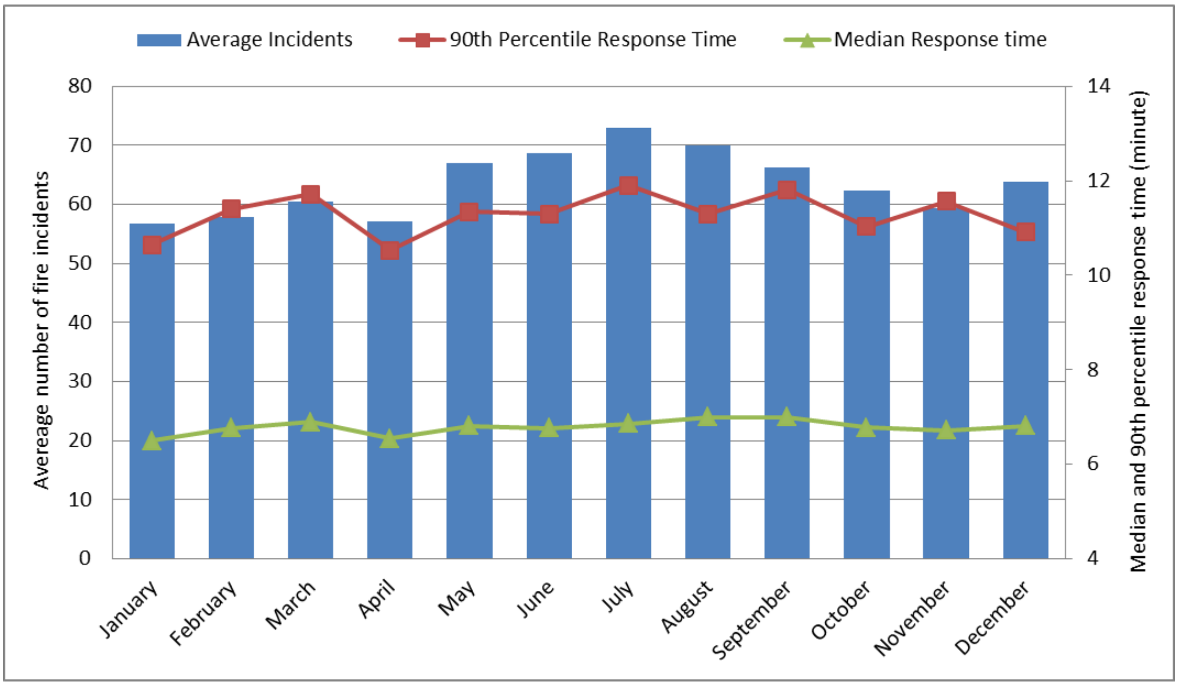

Figure 2. Residential fires and response times (by month of the year)

Although the monthly analysis shows that the demand for service satisfies the service delivery standards set by the Australian Government, (i.e., throughout the study period 90% of demand for service has been met within the stipulated 12 minutes), response times are relatively longer during winter (i.e., above 11.3 minutes) and particularly in July the 90th percentile where response times are just under 12 minutes. A one-way ANOVA test revealed a significant result in the variation of response times by month (F = 1.88; Probability > F = 0.0369). In contrast, median response times show much smaller variations by month (i.e., between 6.5 to 7 minutes). Results from the monthly analysis show that half of the demand for service has been met within 7 minutes.

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Figure 3 examines daily distributions of incidents and their associated response time. Unlike monthly distributions, results show that response times are marginally longer (i.e., above 11.4 minutes) during weekdays when there are fewer residential fires and quicker during weekend, particularly on Saturdays, where 90% of the demand for service are met within 11 minutes, at a time when demands for fire service are more frequent. Although the variation of response times observed in a daily basis is significant (F = 2.50; Probability > F = 0.0203), correlation test does not unveil statistically significant relationship between the number of residential fires and their associated response times. The result observed from the daily analysis may be an artefact of could be also due to the fire brigades service responding to other demands for service (e.g., road accident) and various activities that fire departments conducting during weekdays (QFES 2013-14).

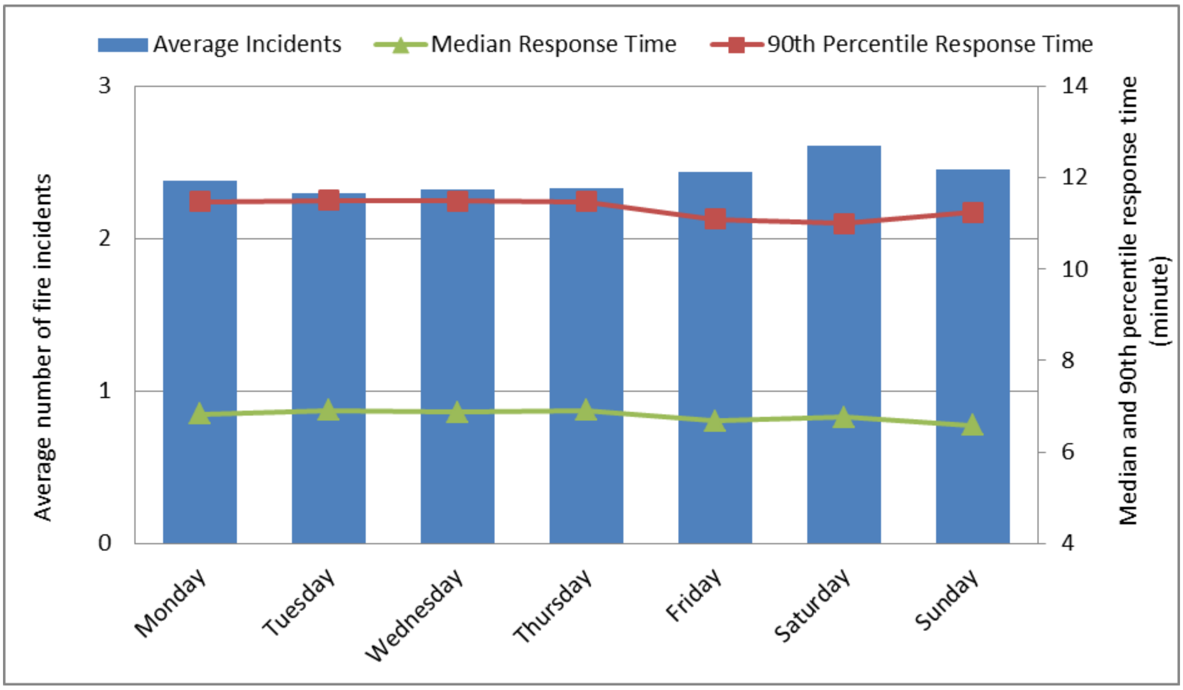

Figure 3. Residential fires and response times (by day of the week)

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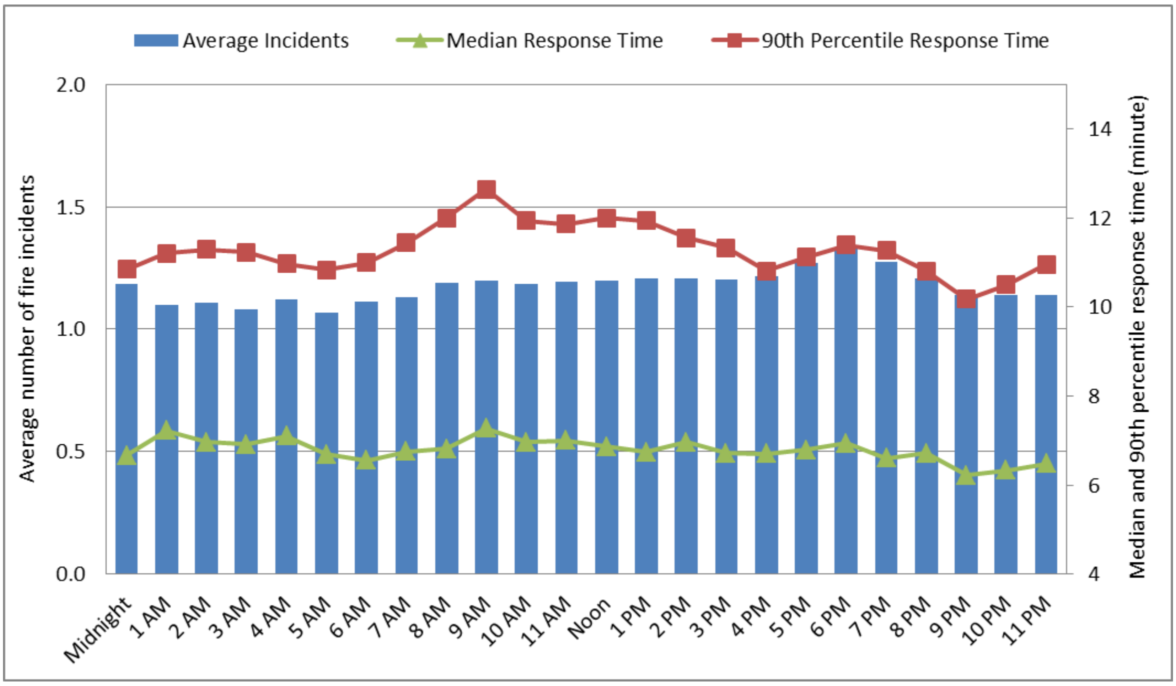

Figure 4. Residential fires and response times (by hour of the day)

Figure 4 examines hourly patterns of residential fires and their associated response times. Results show that residential fires become more frequent during the evening, particularly between the hours of 17:00 and 19:00 when call-outs for residential fires are more frequent. Generally, response times are slower throughout the day and particularly during peak-hour traffic i.e. at 09:00 hours, where 90% of the demand for service has been met within 13 minutes.

In summary, results from the temporal analyses highlight that longer response times tend to occur around peak hour especially in the morning, weekdays and through the winter period. The results indicate that residential fires response times vary by time, and that the degree of this variation may reflect variations in the demand for service. However, we note that there is need for further investigation in order to verify this claim to include examination of the total demand for service – i.e., total demand for service to include all other types of fire incident by month, day and hour.

3.2. Spatial Dynamics

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The spatial investigation of response times used Statistical Area Level 2 (SA2) as the unit of analysis (Figure 5). The spatial analysis permitted the identification of locales where the service delivery standards was both met and not achieved.

Figure 5 shows the 90th percentile response times of all fire incidences across the locales of the BSD. Response times (in minutes) were shown to vary spatially with relatively longer response times experienced in the outer suburbs and faster times in inner city locales. Results from the spatial investigation of all fire incidences revealed that 82% of the locales that were subject to a residential fire are home to 81% of the BSD population were responded to within the 12 minute service delivery window.

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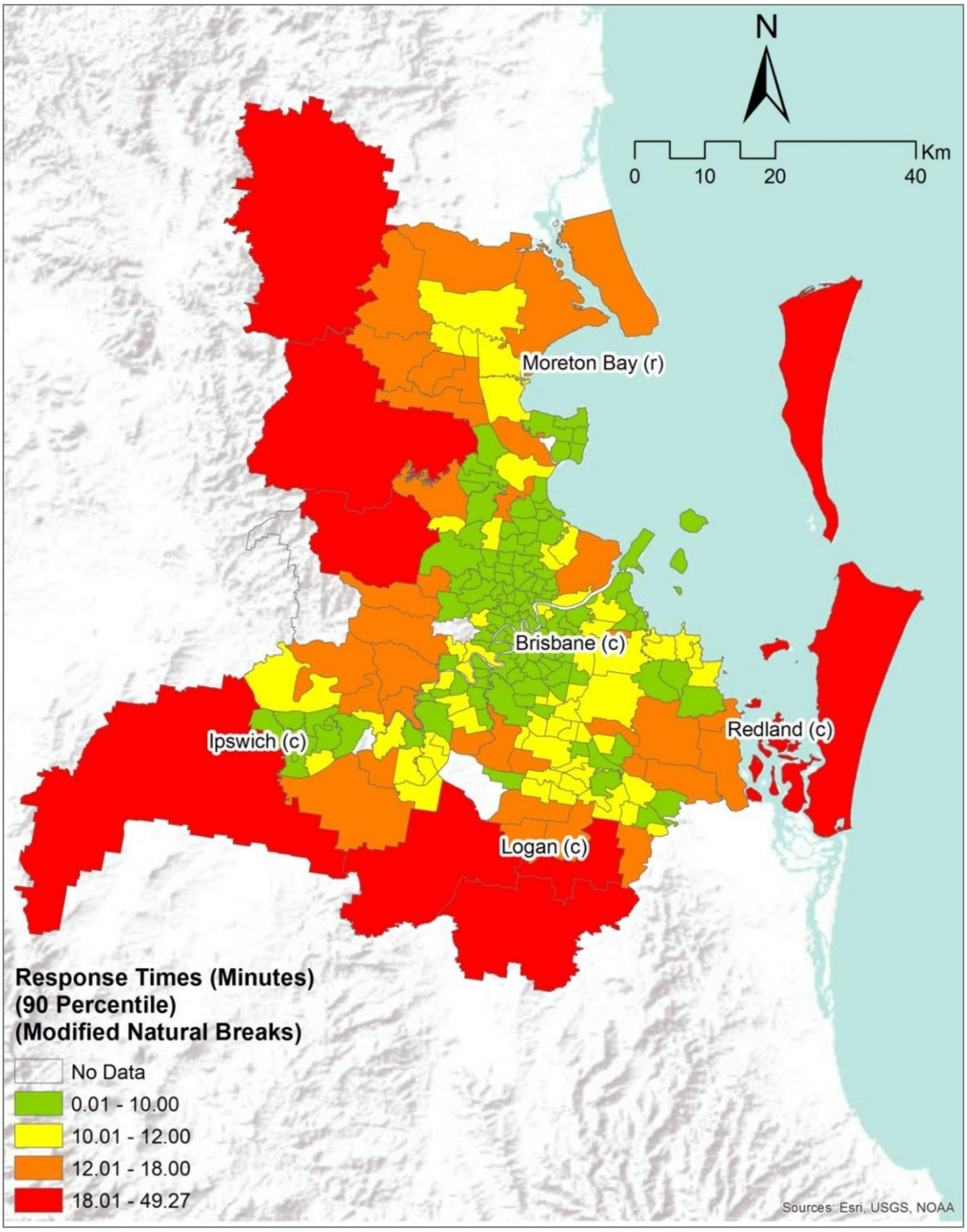

Figure 5. Spatial patterns of response times for the 90th percentile

Next, to reveal the changes in such patterns and their relationships with population over time residential fire incident data were divided into three time periods: a.2001; b.2006; and c.2011

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and linking these to census data describing the total population for SA2s. As shown in Table 1, in 2001 84% of the locales containing 83% of the total population received response to calls for emergency service within 12 minutes, meaning fire agencies satisfied the service under service delivery standards set by the Australian Government (i.e. 90% coverage in 12 minutes response time (i.e., travel time)). However, by 2011, only 78% of the locales, home to approximately three quarter of the total population were responded within 12 minutes. Interestingly, results show that in the inner Brisbane suburbs of the BSD, (the site for the majority of fire stations), 90.37% locales received timely service through all three time periods.

Table 1. Number of locales with response times below or above the service delivery standard

Period	**90th percentile response times (minutes) by number of SA2's**		**Population**
	Below service delivery threshold (<12)	**Above service delivery threshold (>12)**	
2001	193 (83.55%)	38 (16.45%)	1,625,115
2006	185 (80.09%)	46 (19.91%)	1,800,753
2011	180 (77.92%)	51 (22.08%)	2,002,432
Overall	**188 (81.39%)**	**43 (18.61%)**	**1,809,433**

In summary, response times were shown to vary across the BSD, however the degree of this variation being positively associated with population densities, i.e., response to calls for emergency service tended to be quicker in areas where there is higher population densities. Results from the spatial analysis highlight that response times are faster in the inner urban areas of the BSD. The findings from the spatial investigation have potential utility for fire agencies and policy makers in planning future programs of fire response and prevention activities, especially from a resource allocation perspective through the spatial targeting of allocation of finite resources.

4. Discussion and Conclusion

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The aim of this paper has been to explore the temporal and spatial dynamics of residential fire incident response times in the BSD. Our findings suggest that response times vary by both time and space. Results show differences in response times across specific periods of the day, week and in particular seasons in addition to spatial variations, and that the degree of variation is dependent more on the demand for service and less on population density. The main findings from the response time analysis are further summarized below.

Results from the temporal analyses highlight that longer response times tend to occur around peak traffic hours especially in the morning, weekdays and through the winter period. Results show a statistically significant relationship between residential fire incidents and response time patterns across months, and particularly during winter, response times are longer at a time when demands for fire service are more frequent. This may be an indication of overstretched fires resources that have to respond to a large number of fire incidents during winter (Corcoran et al. 2007; Corcoran et al. 2009). In BSD, response times could also be slower between November and March due to several reasons that include the results of summer storms which frequently require fire services to assist during such disasters (QFES 2013-14). Interestingly, response times are slower during weekdays when demands for fire service are less frequent. However, this may reflect the various fire service activities underway during these times such as community fire safety programs and training – that is, resources could be thinner during this time therefore it might not always be the closest station responding to calls for emergency service, ultimately resulting into longer response times (QFES 2013-14). Results from the temporal analysis of response times indicate that during winter, and particularly in the month of July, when frequent fire incidents are have been experienced, the fire stations need to increase their manpower, equipment and fire engine to give better services in standard time (Sufianto & Green 2012; Tamat et al. 2014).

Results show that response times also vary by space aligning with the findings reported in previous studies (e.g., USFA 2006; Sufianto & Green 2012; Tamat et al. 2014), that find a positive relationship between variations in response times and population densities, i.e., response to calls for emergency service is quicker in inner urban areas, that have higher population densities. Results from the spatial analysis show that response times are relatively

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longer in the peri-urban locales with more rapid responses associated with the inner locales of the BSD throughout all time periods. More specifically, response to calls for emergency service tended to be slower in areas where there is lower population density. As population densities increase, there are a greater number of fire stations which effectively cover smaller geographic areas, which arguably contributes to faster response times. In addition, response times have the potential to be influenced by a range of additional factors that may include topography, quality of the road/transport infrastructure, crewing configurations, response systems and processes, and travel distances (Productivity Commission 2015). Integrating a number of these additional factors within the current analysis will form one of the avenues of future research. Another avenue for future research is using spatial econometric techniques to statistically evaluate the findings presented in this paper.

There are a number of limitations associated with this study that require noting. Firstly, this paper presented spatio-temporal dynamics of call-outs relating to residential fire incidents, where future studies is now required to verify the findings presented here through analysing all demand for service – i.e., all other types of fire incident. The focus of this paper has been to examine the overall spatial and temporal dynamics of response times and relating it through demand for services and population density. Future work in this area will conduct detailed investigations of the areas that exhibited high fire intensity and slower response times to provide a more comprehensive explanation of why such patterns exist. In addition, future work will draw on disaggregated census variables for analysis (e.g., income, age and sex) (Chhetri et al. 2009) and environmental factors (e.g., temperature, humidity, rainfall, wind speed) (Sufianto & Green 2012) to explain the observed patterns unveiled in this paper. Nevertheless, we argue that the results presented here have progressed our understanding of the spatial and temporal dynamics of residential fire incidents response times. The types of techniques used in our research provides a means through which we can investigate such trends at detailed spatial scales as well as examine potential reasons for such trends in any future research.

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To conclude, residential fire incidents and their associated response times are clustered across time in a manner that is consistent with previous studies on the area (e.g., USFA 2006; Sufianto & Green 2012; Tamat et al. 2014). Specifically, results from the monthly analysis indicate a statistically significant relationship between fire incidents and the response time patterns, and particularly during winter, response times are longer at a time when demands for fire service are more frequent. Response times also revealed spatial variations wherein faster response times were found to be associated in areas with higher population densities, in particular the inner urban locales of the study area. Our findings point towards ways in which emergency fire management might be improved through the application of spatial analytical techniques. More specifically the identification and mapping of the spatio-temporal patterns of residential fire incident response times along with their relationship to both current and future population growth are particularly promising. The outputs from this process have the potential to offer a new evidence base from which to inform policy decisions from a resource allocation perspective through the temporal and spatial allocation of finite fire resources.

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