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A chaos theory view of accidental dwelling fire injuries

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Abstract

In this article, we examine a chaos theory view of accidental dwelling fire injuries using data from a UK fire and rescue service over a 10-year period. Although chaos theory could not predict if or when a fire injury will occur for a given individual, chaos theory provided further information above and beyond the typical statistical analyses undertaken by fire and rescue services in terms of identifying pattern repetitions, interconnectedness of circumstances and sensitivity to initial conditions relating to the circumstances of accidental dwelling fire injuries. Householder behaviours such as attempting to tackle the fire or being under the influence of alcohol or drugs were the most prevalent circumstances relating to fire injury over the period studied. Proportions of smoke/toxic fumes inhalation injuries and injuries sustained attempting to fight the fire compared to the overall numbers of fire injuries per year showed pattern repetition over the period studied. In terms of interconnectedness, although there were roughly equal numbers of male and female fire injuries overall, the likelihood of an alcohol-/drug-related fire injury or a fire injury resulting from attempting to put out a fire was strongly connected with the gender of the householder involved.

KEYWORDS
chaos theory, fire, injury

1 | INTRODUCTION

Chaos theory concerns systems that are highly sensitive to initial conditions and have underlying patterns, interconnectedness and repetition. Chaos theory has been used to model earthquakes,[1,2] forest fires,[3,4] healthcare and public health[5-7] and industrial and transport accidents.[8-10] Methods for fire risk analysis can be categorised as qualitative, semi-quantitative and quantitative.[39] Qualitative methods address both likelihood and consequences qualitatively. Semi-quantitative methods treat likelihood qualitatively but consequences quantitatively or treat likelihood quantitatively but consequences qualitatively. Quantitative methods treat both consequences and likelihood quantitatively and can be more comprehensive than the other two approaches. Chaos theory can provide a qualitative fire injury risk analysis framework in terms of pattern repetitions, initial conditions and interconnectedness of circumstances that can guide more thorough and detailed statistical analysis, above and beyond the statistics that are typically produced by fire and rescue services.

The activities of the population of an area covered by a fire and rescue service can be considered as a dynamical social system for the purposes of chaos theory modelling. Over time, the actions of a given population with regard to the use of household objects typically associated with accidental dwelling fires (cookers, smoker's materials, heaters and candles) will occasionally result in an accidental dwelling fire injury.[11] In the vast majority of instances over a given time period such household objects will be used safely. However, in certain circumstances (such as distraction,[12] falling asleep,[13] being under the

influence of alcohol or drugs,[14] medical conditions/effects of medication[15]) unsafe use of such objects may occur and an accidental dwelling fire and possible injury may result. Dwelling fire injuries map to a chaotic system, since accidental dwelling fires typically occur due to infrequent instances of carelessness. It is the repetition of patterns of circumstances, the interconnectedness of the elements of the circumstances and the sensitivity of the circumstances relating to carelessness that can be identified by a chaos theory approach above and beyond the statistical analyses typically undertaken by fire and rescue services. By adopting a chaos theory view of circumstances relating to the main ignition sources (cookers, smoker's materials, heaters and candles) over time by a given population, it is possible to identify the repetition of patterns of such circumstances over time; the interconnectedness of the elements of the circumstances; and the sensitivity to the initial conditions in terms of carelessness that can lead to a fire injury. Chaos theory can provide a deeper and richer understanding of the circumstances associated with accidental dwelling fire injuries.

Fire and rescue services and associated agencies can benefit from the application of chaos theory to the analysis of fire incidence and injury data since this can provide analyses beyond typical reporting approaches. In particular, a chaos theory approach can assist in identifying relationships between the different circumstances associated with fire incidences and injuries (interconnectedness), identifying repetition of patterns over time and identifying how even small differences in circumstances can affect the likelihood of fire incidence and injury (sensitivity). This approach does involve more time consuming complex analysis than the standard reporting typically used by fire and rescue services, however, by considering the more complex interrelationships and patterns of fire incidence and injury data, it can be possible to gain further insight into the nature and distribution of fire incidences and injuries and thereby support fire prevention approaches.

Chaos theory provided a framework to understand the behaviour of a dynamic system (fire injuries over a given time period) that cannot necessarily be explained and predicted by simple data relationships, but can be explained and predicted by more complex data relationships by adopting a more holistic and systemic viewpoint. The framework consisted of:

Examination of the most common categories of fire injury variables (which may be typically undertaken by fire and rescue services).

Comparison of the most common categories of the different variables to identify possible relationships (which would not typically be undertaken by fire and rescue services).

Examination of the patterns of data relationships between variables over time (which may be typically undertaken by fire and rescue services to a limited extent).

Examination of how the different variable categories are interconnected (which would not typically be undertaken by fire and rescue services).

Examination of the combinations of the categories of different variables that are commonly associated with accidental dwelling fire injuries (which would not typically be undertaken by fire and rescue services).

In this manner, although the chaos theory approach utilises classical frequentist statistical techniques, it does so in a manner that extends the analyses that would typically be undertaken by fire and rescue services by adopting a more holistic and systemic viewpoint that caters for more complex interrelationships, sensitivity to circumstances and pattern repetition. Typically fire and rescue services might not have the data analytical resources to undertake analyses of the more complex interrelationships in the data that can be examined via a chaos theory framework, which specifically addresses interrelationships and patterns over time.

The framework firstly included analysis of the different categories of the fire injury variables available recorded in the English fire incident recording system[29] managed by the UK Home Office. Data regarding fire injuries is collected in real time as firefighters respond to fire incidents and enter information into the incident recording system. Some variables are updated on a continuous basis as fire and rescue investigations proceed and new information is obtained. The fire data received by the UK Home Office undergoes a quality assurance process to ensure the data is fit for purpose and any data quality issues such as unusual patterns in the data are flagged and subsequently resolved with the fire and rescue service concerned. Fire injury data recorded covers aspects such as the location of the fire, the cause of the fire, the ignition source and the casualty data.

A chaos theory approach can extend the analysis of accidental dwelling fire injuries by examining data in terms of more complex patterns, for example, the relationship between and within categories; in terms of pattern repetition, for example, do the relationships between and within categories repeat over time; in terms of interconnectedness, for example, do certain specific categories of a variable exhibit a relationship with specific categories of other variables; and in terms of initial conditions, for example, are there certain combinations of given categories of different variables that together are more common in accidental dwelling fire injuries. Chaos theory provides a method of qualitative and quantitative analysis to investigate the behaviours and circumstances related to fire injury incidents that cannot be explained and predicted by single data relationships, but can be explained and predicted by holistic data relationships. Although chaos theory based statistical modelling cannot predict the occurrence of an accidental dwelling fire injury for a given individual or household, it can provide a view of social groups and behaviours that are most at risk of such injuries over time.

In a research presented in this article, a chaos theory model of accidental dwelling fire injury analysis will be used that involves: analysis of the different categories of the variables involved; identification of the most common categories; comparison of the most common categories of the different variables to identify relationships; examination of the patterns of such relationships over time; examination of how the different categories of variables interconnect e.g. does gender relate to differences in the distributions of other variables; and examination of the combinations of the categories of different variables that commonly occur as initial conditions of dwelling fire injuries. Most accidental dwelling fires in the UK are either extinguished by a householder, or the fire will go out by itself. Only 25% of UK accidental

dwelling fires are typically attended by and recorded by a UK fire and rescue service.[16] Most accidental dwelling fires recorded by a UK fire and rescue service will not involve a fire injury.[17] In chaos theory terms, the initial conditions (circumstances) which lead to accidental dwelling fire injuries are worthy of research. In the majority of instances, accidental dwelling fire injuries stem from careless use of everyday household objects such as cookers, heaters, smoker's materials and candles. The originality of the research presented in this paper is the application of chaos theory to identify the patterns of circumstances resulting in accidental dwelling fire injuries; the repetition of such circumstances over time; the interconnectedness of such circumstances; and the sensitivity of the initial conditions that can lead to fire injury. The area studied in the research, Merseyside, covers a geographical area of 645 km^2 and contains a mix of high-density urban areas, suburbs and semi-rural areas and had a population of 1 423 100 of which 75.6% were economically active in 2021.[36] Merseyside has some of the highest levels of deprivation in the UK.[36] The IMD decile is a measure of deprivation calculated by the UK Office for National Statistics.[34] The IMD scale of deprivation measurement covers all areas of England and ranges from 1 that represents the 10% most deprived areas in England, to 10 that represents the 10% least deprived areas in England. Factors associated with deprivation such as alcohol/drug use, old age and disability related to fire injury[35] also showed concentration in the most deprived areas of Merseyside. Although previous research[37,38] had examined the effects of deprivation upon fire injury risk, the research presented in this article examined the effects of deprivation in a more specific and measurable manner and in terms of how this relates to the interconnectedness of fire injury risk factors in a chaos theory model.

2 | LITERATURE REVIEW

2.1 | Accidental dwelling fire injuries

The majority of accidental dwelling fires in the UK are not reported to, or recorded by UK Fire and Rescue Services. In the UK, in 2016–17,[16] in the majority of households where an accidental dwelling fire occurred (75%) the fire was either extinguished by a householder, or the fire went out by itself. Only a quarter (25%) of such accidental dwelling fires were put out and recorded by a UK fire and rescue service. Ghassempour et al.[41] had commented upon the difficulties associated with estimating the numbers of residential fires in a study in Australia. The majority of accidental dwelling fires recorded by a UK fire and rescue service will not involve a fire injury.[17] Previous research had noted patterns in the incidence of accidental dwelling fire injuries over time relating to socio-demographics and behaviours.[11,18–20,42] In particular, the connection between poverty and elevated fire risk has been documented in multiple studies.[37,38] In addition it is important for fire safety solutions to take sufficient account of the social context of the area and population concerned.[40] Regulatory changes may also impact the incidence of residential fires and injuries. In the UK there were fire and rescue service regulatory

changes relevant to the time period concerned. The Fire and Rescue Services Act 2004[43] formally implemented the prevention element of Home Fire Safety Visits in the UK. These visits involve fire and rescue service personnel visiting homes to provide advice, assess risks and offer practical guidance on fire safety and provide residents with information on smoke alarms, escape plans and other safety measures. The Regulatory Reform (Fire Safety) Order 2005[44] added more fire safety duty in properties where shared areas exist, for example corridors in apartment buildings, blocks of flats and maisonettes on responsible persons such as building owners, landlords or occupiers to ensure fire safety in their premises. Ghassempour et al.[45] had commented upon the impact of reduced fire risk cigarettes regulation on residential fire incidents in a study in Australia.

2.2 | Chaos theory modelling

Chaotic systems exhibit complex behaviour which is unstable and unpredictable over time.[21] Chaos theory concerns deterministic dynamical systems that are very sensitive to initial conditions. Small differences in initial conditions can lead to widely diverging outcomes[22] and for such systems, making long term predictions can be difficult if not impossible.[23] Chaos theory has been applied to a variety of physical and social systems in order to attempt to model unstable and unpredictable events such as flash flooding[24] and healthcare emergencies.[25] Chaotic systems can potentially be better understood by studying a reduced number of crucial system components.[26] Whilst it may not be possible for organisations to predict the outcomes of processes operating together in complex systems, it may be possible to identify underlying mechanisms that contribute to instability within the system.[25]

2.3 | Fire modelling using the chaos theory

In terms of the chaos theory, the likelihood of an accidental dwelling fire and fire injury can be highly dependent upon the level of carelessness with which ignition sources are used, for example the length of time that the ignition source was left unattended[27] and the nature of the ignition source.[28] Such physical circumstances would be difficult to routinely measure quantitatively in the home. However, in terms of patterns of circumstances and repetition of circumstances, analysis of accidental dwelling fire injuries over time can provide a view of the patterns and repetitions within a chaotic dynamical system. Chaos theory is applicable to accidental dwelling fire injuries since the more detailed and complex analyses embodied in chaos theory can provide insights into the repetitions of patterns of fire injury circumstances, the interconnectedness of the different elements of the circumstances and sensitivity to the initial conditions that occur within the area covered by a fire and rescue service for the purposes of fire prevention.[11] The benefits of chaos theory over traditional statistical analysis for accidental dwelling fire injury analysis are the identification of more complex patterns of injury circumstances, the

repetition of such patterns over time, the interconnectedness of different circumstances and the combinations of circumstances that are commonly associated with fire injuries. Traditional statistical analysis would not typically examine such complex relationships and their patterns and repetitions over time. In this manner, the chaotic nature of fire injuries can be understood not for individual incidents, but for groups of individuals over a period of time. This can help to understand the nature of those community groups that are most at risk of accidental dwelling fire injury for fire prevention purposes. Chaos theory can provide a deeper understanding of community groups and associated behaviour patterns than can typically be provided by traditional statistical approaches. Chaos theory can provide a set of constructs that can provide flexibility as an analytical framework.[22] Chaos theory has been applied to the modelling of forest fires and decision management during such fires[4] where fire propagation in conifer forests can be considered a non-linear system exhibiting chaos theory-like features such as high sensitivity to certain initial conditions, sudden increases in fire spread rate and intensity.[3]

Overall, although chaos theory has been applied to industrial accidents and forest fires, there does not appear to have been any modelling of accidental dwelling fire injuries using chaos theory. The originality of this research is the application of chaos theory to identify patterns, repetitions and the interconnectedness of the circumstances associated with accidental dwelling fire injuries and the sensitivity to the initial conditions (circumstances) that can lead to fire injury. The types of factors that can be examined by a chaos theory approach include the combinations of circumstances and behaviours associated with accidental dwelling fire injuries, for example being under the influence of alcohol, falling asleep and attempting to fight the fire.

3 | RESEARCH METHOD

A case study in Merseyside Fire and Rescue Service in the UK examined accidental dwelling fire injury data for the period 2006 to 2016. The research method used was to examine the fire injury data in terms of the initial conditions (circumstances), patterns, repetitions and interconnectedness concepts of chaos theory. In England, fire injury data is recorded in the English fire incident recording system[29] by fire officers attending a fire incident. Fire injuries are categorised into different categories by the fire officer concerned including: Overcome by gas, smoke or toxic fumes, asphyxiation; Combination of burns and overcome by gas/smoke; Burns – Severe; and Burns – Slight. Assessment of alcohol or drugs being involved in a fire injury is determined by a fire officer attending the fire incident. Accurate assessment of alcohol or drugs being involved in a fire injury may be difficult for the fire officer concerned.

In practical terms, the approach involved statistical analysis (frequency analysis and correlation analysis) of the data relating to the circumstance associated with fire injury during the period studied. Statistical approaches can be useful for the comprehension of non-linear and chaotic phenomena.[30] The chaos theory concepts provided a framework for examining those circumstances (initial conditions)

most prevalent amongst the fire injuries; the patterns of fire injuries and the repetition of such patterns over time (in particular, in terms of the stability of the patterns over time); and the interconnectedness of factors within the circumstances associated with fire injury. Chaos theory provided a framework for more detailed insight and understanding of the nature of the circumstances associated with fire injury via statistical analysis.

The research questions posed were:

- How can chaos theory be used to model accidental dwelling fire injuries?
- What are the most prevalent circumstances (initial conditions) associated with accidental dwelling fire injury?
- What patterns exist in the circumstances of accidental dwelling fire injury and do they repeat over time?
- Are factors within the circumstances associated with accidental dwelling fire injury interconnected?

The model for chaos theory application to accidental dwelling fire injury analysis involved:

- Analysis of the different categories of the variables involved
- Identification of the most common categories
- Comparison of the most common categories of the different variables to identify possible relationships
- Examination of the patterns of such relationships over time
- Examination of how the different variable categories are interconnected.
- Examination of the combinations of the categories of different variables that are commonly associated with accidental dwelling fire injuries

These are important research questions since a more detailed understanding of the patterns of accidental fire injury can be used to inform fire prevention strategies and thereby attempt to reduce the health, social and economic costs associated with accidental dwelling fire injuries.[31] In addition, more targeted fire prevention approaches (that can be informed by the chaos theory) are required by fire and rescue services that are operating in circumstances of reducing funding.[32] A limitation to the research presented in this paper is potential generalisability to other fire and rescue services, since Merseyside is one of the most deprived areas in England. In addition, residential fire injury data used in the research concerned only those residential fires that were reported to Merseyside Fire and Rescue Service and where associated injuries were recorded by Merseyside Fire and Rescue Service officers attending the residential fire. A limitation of the use of chaos theory for analysis of accidental dwelling fire injuries is the additional time and effort required to analyse the complex relationships, patterns and repetitions over time that would not typically be covered by traditional statistical analysis. Traditional statistical analysis of accidental dwelling fire injuries would typically be mainly limited to analysis of the distributions of the different variables, rather than analysis of the more complex relationships, patterns and repetitions involved in chaos theory analysis.

4 | RESULTS

4.1 | Chaos theory model of accidental dwelling fire injuries

Over the period studied, 2006 to 2016 there were 1309 accidental dwelling fire injuries. Approximately 1 in 10 accidental dwelling fires resulted in a fire injury over the period studied.

A chaos theory approach was used to determine the patterns, repetitions, interconnectedness and prevalent initial conditions (circumstances) of fire injury incidents over the 10 year period studied.

When we consider the dynamics of the use of ignition sources such as cookers, heaters and smoker's materials there will be instances such as when these are left unattended for more than a given period of time that the likelihood of an accidental dwelling fire will increase dramatically. When we then consider the circumstances surrounding such instances of fire, the likelihood of fire injury can also increase dramatically due to factors such as alcohol or drug consumption, falling asleep and mobility issues.[12–14]

Figure 1 shows how the likelihood of an accidental dwelling fire can chaotically increase dramatically with regard to the nature of the ignition source used and the time left unattended. Figure 1 illustrates how the likelihood of fire can exhibit quite different outcomes based upon small variations in the use of ignition sources and the time left unattended. For example, leaving cooking unattended for even a short period of time can drastically alter the likelihood of a cooking fire. Furthermore, the likelihood of a fire injury can chaotically increase dramatically due to factors such as awareness (which can be affected by tiredness and alcohol and drug consumption) and mobility issues (Figure 2).

Figure 2 illustrates how the likelihood of fire injury can exhibit quite different outcomes based upon small variations in awareness possibly due to tiredness or alcohol/drug consumption and the level of mobility in terms of escaping a domestic fire.

The overall system is chaotic[33] since slight variation in the carelessness with which an ignition source is used, for example the time left unattended, the level of awareness due to alcohol, drugs, tiredness can dramatically affect the likelihood of an accidental dwelling fire and fire injury in ways that are difficult to quantitatively measure in domestic settings. In terms of the practical application of a chaos theory view of accidental dwelling fire injuries, this research used statistical analysis to examine the initial conditions, patterns, repetitions and interconnectedness underlying the dynamic fire injury states over the period studied.

4.2 | Circumstances (initial conditions) associated with accidental dwelling fire injuries

The fire injuries circumstance variable within the fire incident data set was examined to identify the most common circumstances relating to fire injury. This was an important aspect of the chaos theory analysis framework, in terms of identifying the variables that may be useful for
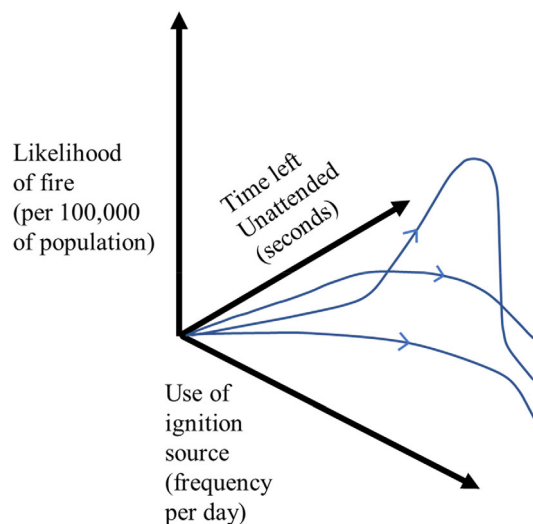

FIGURE 1 Likelihood of accidental dwelling fire in relation to use of ignition source and time left unattended.
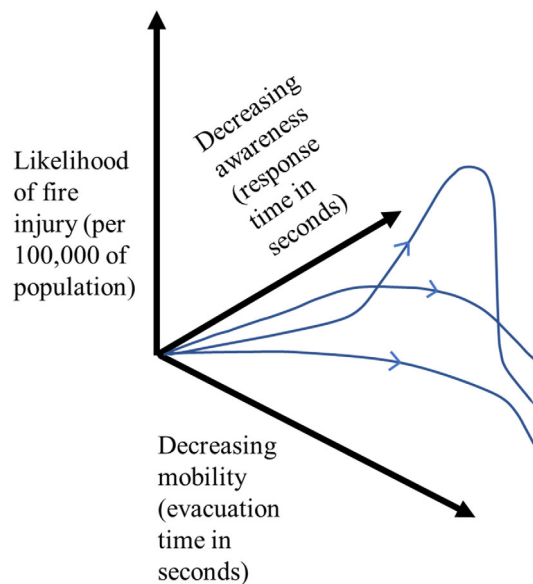

FIGURE 2 Likelihood of an accidental dwelling fire injury in relation to decreasing awareness and decreasing mobility.

understanding the patterns and interrelationships in fire injury data. In terms of the initial conditions, or circumstances relating to fire injury, over the period studied, householders attempting to tackle the fire themselves was involved in 19.4% of the accidental dwelling fire injuries recorded. Alcohol and drug consumption was involved in 13.3% of the fire injuries. Falling asleep was a factor in 7.2% of the fire injuries. Small differences in the manner in which the fire was attempted to be extinguished, the point in time after the start of the fire at which the fire extinguishing was attempted, the time spent attempting to extinguish the fire and the level of alcohol/drug consumption could have led to significant differences in terms of the outcome leading to no injury, or a minor or severe household fire injury.

4.3 | Patterns and repetition within the circumstances of accidental dwelling fire injuries

The chaos theory framework involved analysis of patterns and repetitions of patterns over time. Analysis of the fire injury dataset revealed that smoke inhalation injuries were the most common form of fire injury and therefore it was appropriate to analyze how the number of smoke inhalation injuries compared to the overall number of fire injuries per year, in order to see if this proportion was increasing or decreasing. In a similar manner, since fighting the fire and alcohol/drug consumption were the most common circumstances associated with fire injury over the period studied it was appropriate to analyze how the number of fighting the fire injuries and alcohol-/drug-related fire injuries compared to the overall number of fire injuries per year.

Over the period studied, the numbers of overall fire injuries per year and the numbers of alcohol-/drug-related fire injuries and injuries sustained by householders fighting the fire per year (the most significant circumstances relating to fire injury) varied considerably. Over the period studied smoke/toxic fumes inhalation was consistently the most common form of fire injury accounting for 562 (43%) of the fire injuries overall.

Figure 3 shows that per year the proportion of fire injuries involving smoke/toxic fumes inhalation compared to the overall number of fire injuries was fairly stable. The correlation between overall fire injuries and smoke/toxic fumes inhalation injuries was 0.65 with a significance level of 0.03, indicating that these values were moderately correlated and that the correlation was statistically significant.

The number of overall fire injuries and fire fatalities during the period studied are shown in Table 1.

Figure 4 shows that per year the proportion of fire injuries sustained by householders attempting to tackle the fire compared to the overall number of fire injuries was fairly stable. The correlation between overall fire injuries and fire injuries sustained by householders attempting to tackle the fire was 0.60 with a significance level of 0.05, indicating that these values were moderately correlated and that the correlation was statistically significant.
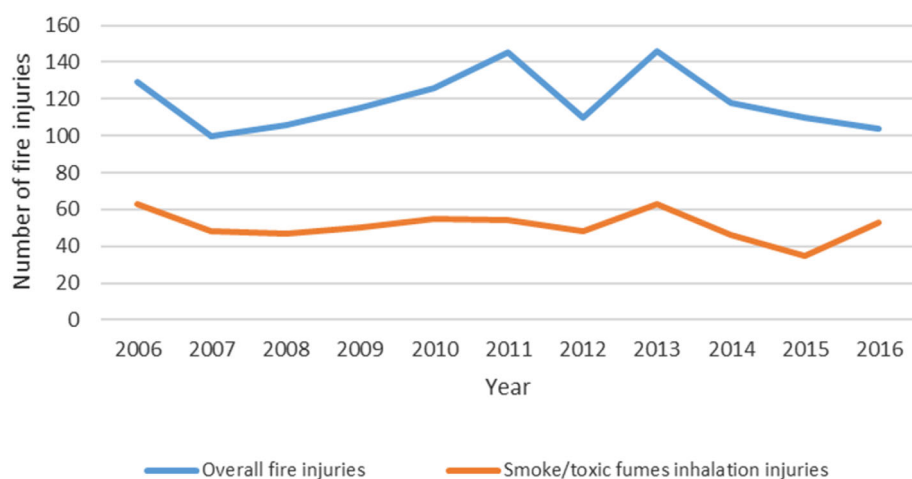
Figure 5 shows that per year the proportion of fire injuries involving consumption of alcohol/drugs compared to the overall number of fire injuries was less stable. The correlation between overall fire injuries and alcohol-/drug-related injuries was 0.35 with a significance level of 0.29, indicating that these values were only weakly correlated and that the correlation was not statistically significant. However, there were only very small numbers of alcohol-/drug-related fire injuries per year.

Overall, it appeared that some patterns of fire injury repeated across the years of the time period studied, that is the proportions of smoke/toxic fumes inhalation injuries and injuries sustained by householders tackling the fire themselves compared to the overall number of fire injuries per year.

4.4 | Interconnectedness of factors within the circumstances of accidental dwelling fire injuries

The chaos theory framework involved analysis of the interconnectedness of factors within the circumstances of accidental dwelling fire

TABLE 1 Overall fire injuries and fire fatalities in Merseyside 2006 to 2016.

Year	Number of fire injuries	Number of fire fatalities
2006	129	6
2007	100	11
2008	106	10
2009	115	6
2010	126	7
2011	145	5
2012	110	3
2013	146	10
2014	118	9
2015	110	15
2016	104	10

FIGURE 3 Overall fire injuries and smoke/toxic fumes inhalation injuries in Merseyside 2006 to 2016.

FIGURE 4 Overall fire injuries and injuries sustained by householders fighting the fire in Merseyside 2006 to 2016.
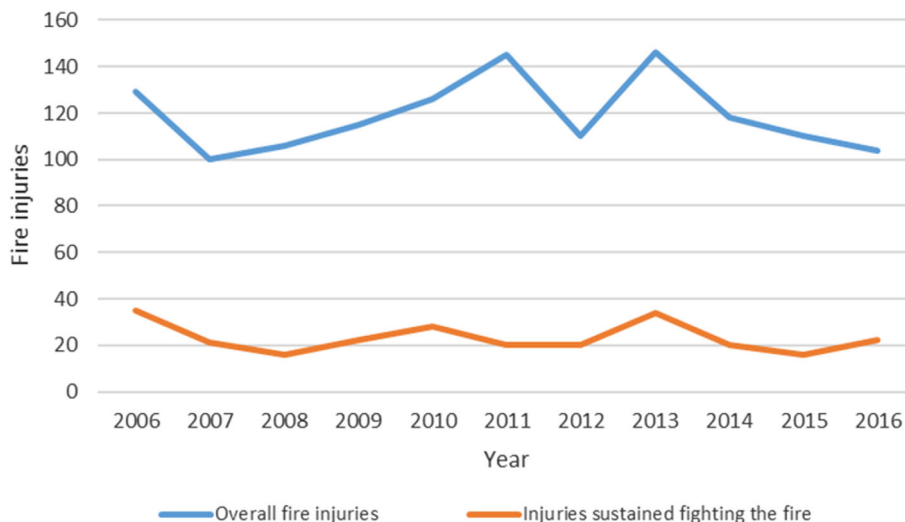

FIGURE 5 Overall fire injuries and alcohol-/drug-related fire injuries in Merseyside 2006 to 2016.
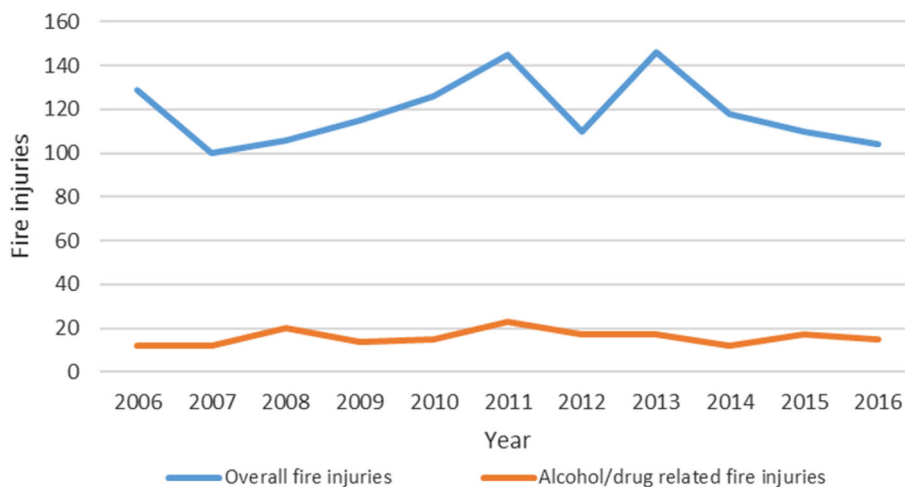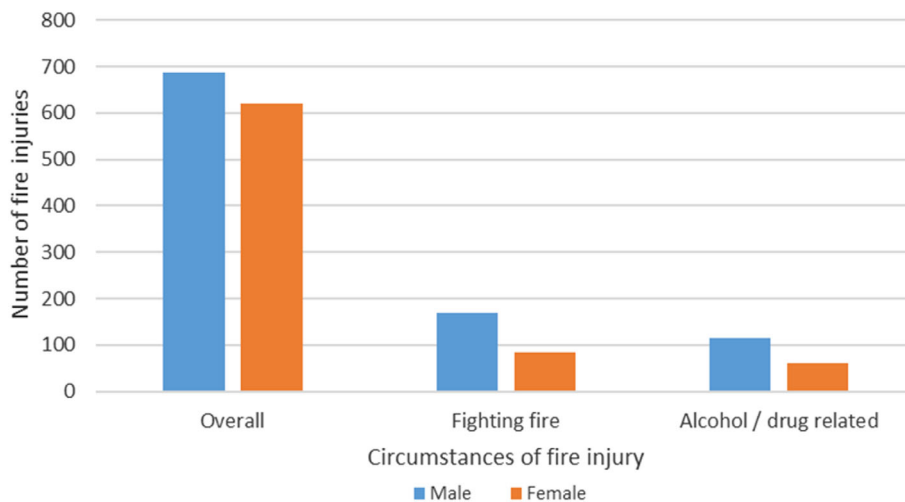

FIGURE 6 Gender and circumstances of fire injuries in Merseyside 2006 to 2016.

injuries. Gender and deprivation had previously been identified as influential aspects of accidental dwelling fire injuries,[17] so these factors were examined in terms of how they might interconnect with other accidental dwelling fire injury circumstances (Figure 6).

Householders attempting to tackle the fire themselves was involved in 19.4% of the accidental dwelling fire injuries recorded and alcohol and drug consumption was involved in 13.3% of fire injuries over the period studied. Although there were roughly equal numbers
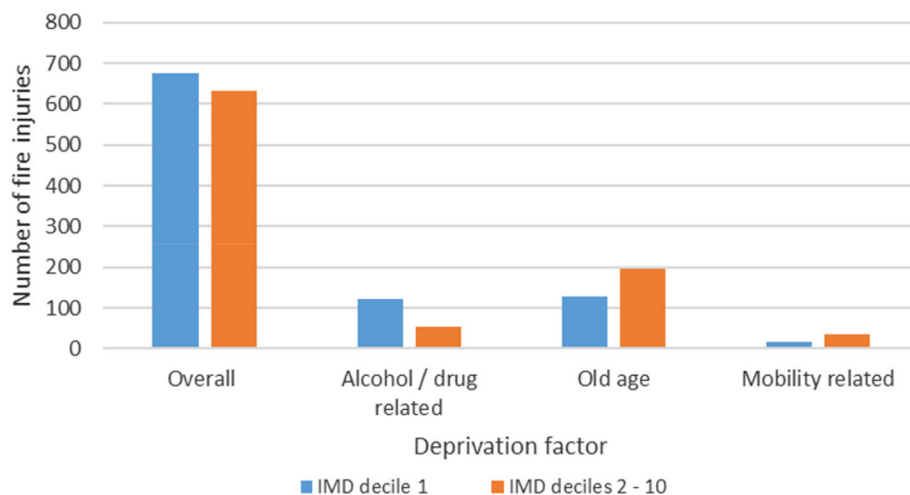
FIGURE 7 Social factors and fire injuries in Merseyside 2006 to 2016.

of male and female fire injuries overall during the period studied, this changed to 1.9 to 1 for alcohol- and drug-related accidental dwelling fire injuries and 2.0 to 1 for injuries sustained by householders fighting the fire. This would indicate that the likelihood of an alcohol-/ drug-related fire injury is strongly connected with the gender of the householder involved. Similarly, the likelihood of a fire injury resulting from attempting to put out a fire is strongly connected with the gender of the householder involved.

Figure 7 showed that overall, over half the fire injuries during the period studied occurred in the most deprived areas of Merseyside (IMD decile 1) compared to the other 9 deciles (IMD deciles 2 to 9). There were 23% more accidental dwelling fires in the most deprived areas (IMD decile 1, which contained 54% of the accidental dwelling fire injuries in the region) than would be expected in the most deprived areas across the region which make up only 31% of all the Lower Super Output Areas within the region. Lower Super Output Areas (LSOAs) are small areas designed to be of a similar population size, with an average of approximately 1500 residents or 650 households.[34] In particular, of the metropolitan boroughs constituting the Merseyside region, Knowsley (the most deprived borough) had twice as many accidental dwelling fire injuries (20% of the accidental dwelling fire injuries in the region) than would be expected based upon population size, whereas Wirral (the least deprived borough) had half the accidental dwelling fire injuries (10% of the accidental dwelling fire injuries in the region) than would be expected.

Table 2 Fire injuries by IMD decile overall and alcohol-/drug-related, old age and mobility related.

5 | CONCLUSIONS

This research examined the use of chaos theory with statistical analysis to explore the nature of the circumstances of accidental dwelling fire injuries in Merseyside in the UK over a 10 year period 2006 to 2016. Although it was not possible to predict if or when a fire injury will occur for a given individual, in statistical terms, there were distinct patterns, repetitions, interconnectedness and likely initial conditions

TABLE 2 Summary of the number of fire injuries by IMD decile overall and with relation to specific factors.

Fire injuries	IMD decile 1	IMD deciles 2–10
Overall	677	632
Alcohol-/drug-related	121	53
Old age	127	196
Mobility-related	17	34

relating to the circumstances of accidental dwelling fire injuries over the time period studied.

In terms of practical fire prevention approaches, chaos theory with statistical analysis can provide a deeper and richer understanding of the circumstances under which accidental dwelling fire injuries occur and thus inform fire prevention strategies. Chaos theory can provide a framework for guiding statistical analysis in terms of identifying patterns of accidental dwelling fire injuries, how such patterns may repeat over time, how factors within the circumstances of the fire injuries may be interconnected and identification of the most likely initial conditions (circumstances) under which such fire injuries occur. Fire and rescue services will produce regular reports regarding their operational performance including fire prevention activities, however, in order to improve the effectiveness and efficiency of fire prevention activities it can be beneficial to examine operational data for more complex patterns and relationships. Chaos theory can be used to guide statistical approaches to further examine patterns, repetitions and interconnectedness of the nature and circumstances of fire injuries and the combinations of circumstances relating to the initial conditions that result in a fire injury.

Householder behaviours such as attempting to tackle the fire, or being under the influence of alcohol or drugs were the most prevalent circumstances associated with fire injury over the period studied. Proportions of smoke/toxic fumes inhalation injuries and injuries sustained attempting to fight the fire compared to the overall numbers of fire injuries per year showed repetition over the time period studied. Gender showed a strong level of interconnectedness with alcohol-/

drug-related fire injuries and injuries sustained attempting to fight the fire over the period studied. There also appeared to be a strong level of interconnectedness between deprivation and accidental dwelling fire injuries over the period studied.

A limitation to the research presented in this paper is the data quality which can potentially skew the analyses undertaken. Although the UK Home Office which manages the English fire incident recording system has quality assurances processes in place, the quality of the data is still dependent upon the assessment of firefighters at the fire and fire and rescue investigations following the fire and in particular the correct classification of the variables recorded. In addition, since it is estimated that only 25% of UK accidental dwelling fires are typically attended by and recorded by a UK fire and rescue service, the data available for analysis consisted of only those fire injuries that were recorded by the fire and rescue service concerned.

Overall, although accidental dwelling fire injuries occur within a chaotic dynamical social system, chaos theory can inform statistical analysis to identify the patterns within such. This approach can be useful for identifying more stable and more random (chaotic) aspects of accidental dwelling fire injuries which can be used to inform fire prevention strategies. It is hoped that the approach presented in this paper may be of use to other fire and rescue services in terms of approaches to analysing their own accidental dwelling fire injury data to better understand the patterns and trends in fire injuries in the area that they cover.

DATA AVAILABILITY STATEMENT
Data available on request from the authors.

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