Façade Fire Incidents in Tall Buildings

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Abstract

Following recent tall building façade fire incidents, Research Seed Funding provided by CTBUH has supported exploratory research into identifying existing reviews of façade fires on tall buildings, creating a database of relevant façade fire incidents and examining where the emerging field of machine learning might be applied to the analysis of the incident database. The database included the general characteristics of the buildings, the regulatory environment in which the buildings were constructed, the types of materials used to create the façade, and the associated test standards with which the materials complied. This database will be used to identify areas of new work that should be advanced in conjunction with funding bodies and research partners. This paper provides a summary of the research work undertaken to generate the database.

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Background

The architectural tone of a building is often set by the choice of façade. Apart from its visual impact, the design of the façade system is influenced by many factors. Examples include desired features such as balconies and glazing; environmental conditions and resulting weathertightness and thermal performance characteristics; long-term durability and maintenance requirements; installation and material cost; and structural implications.

Tall buildings have become more common in cities. For example, statistics compiled by the CTBUH show that the number of buildings of 200 meters' height or greater increased by 441% from 2000 until the end of 2016. That number grew another 26.5% between 2016 and 2018 (CTBUH 2018).

Numerous high-profile fires have recently occurred involving the façades of tall buildings around the world. Incidents such as these pose a life-safety hazard to the building occupants and to people in neighboring property, cause damage to the building, present a challenge for the fire and emergency services, and affect the operation of the building after the event. This additionally results in major news items around the world that damage the reputation of tall buildings.

In addition to the specific characteristics of the façade system, there are several other related aspects that need to be considered. During design and construction, and similarly, if a building later undergoes refurbishment, the building regulatory system and the adoption of various national or international test standards can have a critical impact on the performance of a façade in a fire incident. The installation of passive and active fire protection systems may also have a bearing on the building design and fire performance. Lately, there has been increased discussion on the role that suppression systems, and in particular, automatic fire sprinkler systems, might play in the mitigation of façade fire incidents. The prevailing wind conditions have been shown to have a potential positive or negative influence on a façade fire incident. All these factors contribute to the complexity inherent in the design of façade systems with regards to fire safety.

Façade Assemblies

A typical building façade uses an assembly of products, each of which consists of several components. These components may be made of one or more materials, each with a range of thermo-physical properties. The exact configuration of the assembly and the characteristics of the constituent products can have a major bearing on its performance in a fire incident.

Two of the most common assemblies involve the use of metal composite material (MCM) panels or exterior insulation finish systems (EIFS). MCM panels are made up of two layers of metal skin with a core material in-between. The metal skins may be surface powder-coated or anodized aluminum (Al), stainless steel or titanium, and the core materials may include polyethylene (PE), polypropylene (PP) or a fire-retardant formulation. Panels are then typically attached to the building structure by fixing them to horizontal and/or vertical rails forming the outermost rainscreen component of the façade assembly. EIFS uses a layer of insulating material such as expanded polystyrene, polyurethane, or polyisocyanurate on a non-combustible substrate and one or more thin outer finish layers that may include a reinforcing mesh layer and coatings. Both assemblies can vary in complexity depending on the specific circumstances.

Figure 1 provides a simplified representation of the two common assemblies which have been adopted herein, in which four characteristics are identified in terms of the presence of a ventilated cavity, a face material, a core material and an insulation material. All four may not apply, depending on the particular façade assembly. There are typically additional elements relevant to specific façade assemblies in terms of fixings, moisture barriers, etc., along with many specific construction details for windows, doors, other penetrations, joints, corners, and edges for any given building, which were not addressed in this research.

Database

In developing the tall building façade fire incident database, fields were chosen to capture pertinent factors that could possibly influence fire outcomes, while remaining generic enough to allow comparison between incidents. Building configuration fields included height/number of stories above ground; construction material; geographic location; years of completion and renovation if applicable; and whether a sprinkler system was present. The database also holds fields that describe relevant fire incident parameters, including the reported cause of the fire; where fire started in relation to the façade (for example, whether the fire originally started inside the building before spreading to the façade or whether the incident was the result of an external fire, such as the burning of rubbish, etc.); on what floor the façade initially became involved; any wind effects; and whether there was reported manual intervention (i.e., fire service) or sprinkler system activation.

A total of 59 incidents from 21 countries have been included in the dataset. A baseline set of incidents were taken from the earlier studies by Wade and Clampett (2000), White and Delichatsios (2014), Valiulis (2015), and Evans (2017), in which news media reports were often used as their primary material. Additional information and further incidents were identified through various sources, including web-based resources, again including the news media. The certainty that the database has captured all relevant fire incidents and details of the identified incidents decreases farther into the past, due to the diminished availability of source material.

The database has buildings that range from five to 86 stories in height. Incidents related to "low-rise" buildings, such as single-story industrial units and single-family residences, are not included in the database. The buildings comprise hotels, residential, office and multi-use buildings, with a majority (45 incidents) being primarily residential. The oldest incident was in Canada in 1990, and the most recent was in the United Arab Emirates in 2018.

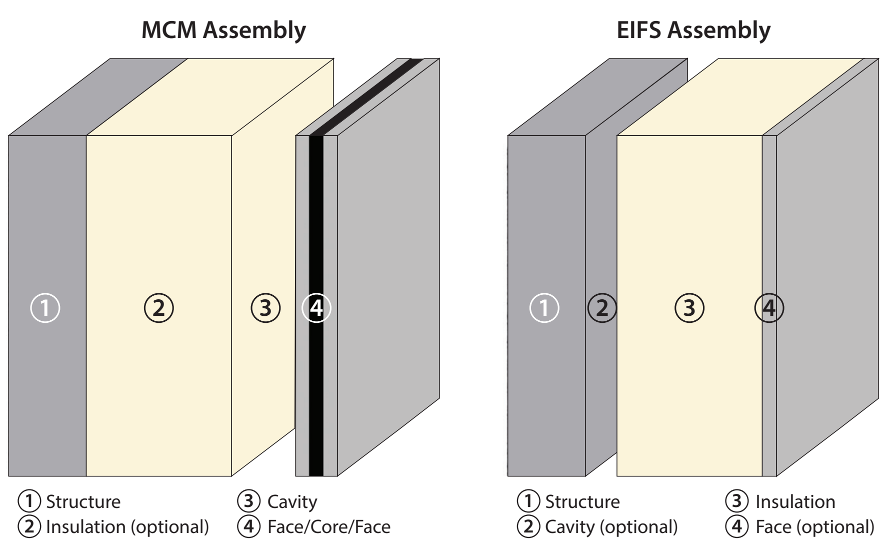

Figure 1. Simplified relationship between face, core, insulation materials and cavity for MCM and EIFS assemblies.

Analysis

Examination of the database shows that in 50% of incidents, the cause of the fire was reported as "unknown." For the remaining 50%, identified causes included electrical equipment, comprising electrical short circuits (11 incidents); smoking materials, including cigarette butts (five incidents); mixed solid fuel items found in rubbish (five incidents); welding activity (three incidents); fireworks (two incidents); cooking appliances, including barbecue grills (one incident); and lightning (one incident).

An analysis of the floor on which the fire started shows that the database has 11 (19%) unknown incidents, 18 (31%) that started at the ground level, five (8%) at the roof or top level, and the remaining 25 (41%) at some intermediate floor level. Thus, almost the same percentage of incidents started at ground level and the roof as those that started at some intermediate story. Where fires started at ground level, the ignition occurred in items external to the façade, such as rubbish. Figure 2 summarizes the cause and/or origin of fire incidents where sufficient information was available.

Most of the identified fires have occurred in buildings recently constructed, within the last 10 years. Furthermore, before 2000, there were no façade fires in buildings higher than 30 stories identified in the database. The figure reflects the timing of when tall buildings were constructed in different regions; i.e., most tall building construction in Asia and the Middle East has occurred within the last 10 years, while North American and European construction has been somewhat more consistent since the 1960s. The database includes 14 incidents in buildings that had been refurbished or were under refurbishment at the time the fire occurred. Where sufficient information is available, the incidents in previously refurbished buildings occurred between 14 and 42 years after their completion.

The database incorporates four façade assembly classifications: MCM, EIFS, Other, or Unknown. Where façade construction information was available, 25% of the fires involved EIFS and 32% involved façade assemblies that included MCM panels. The database then subdivides the assemblies using the characteristics illustrated in Figure 1, with the results shown in Figure 3.

The database has been used to examine the contribution of sprinkler systems and the effect of wind and falling debris on the incidents. A summary of the results is shown in Figure 4. In terms of sprinkler systems, there were 14 incidents (24%) in which it appears there was likely to have been a sprinkler system present and six (10%) in which the building has been identified as not having a sprinkler system installed. The remaining incidents do not have sufficient information, and so have been categorized as "Unknown." Investigation of the incident details suggest that sprinkler systems failed to operate as might be intended in three of the 14 incidents (i.e., ~20%).

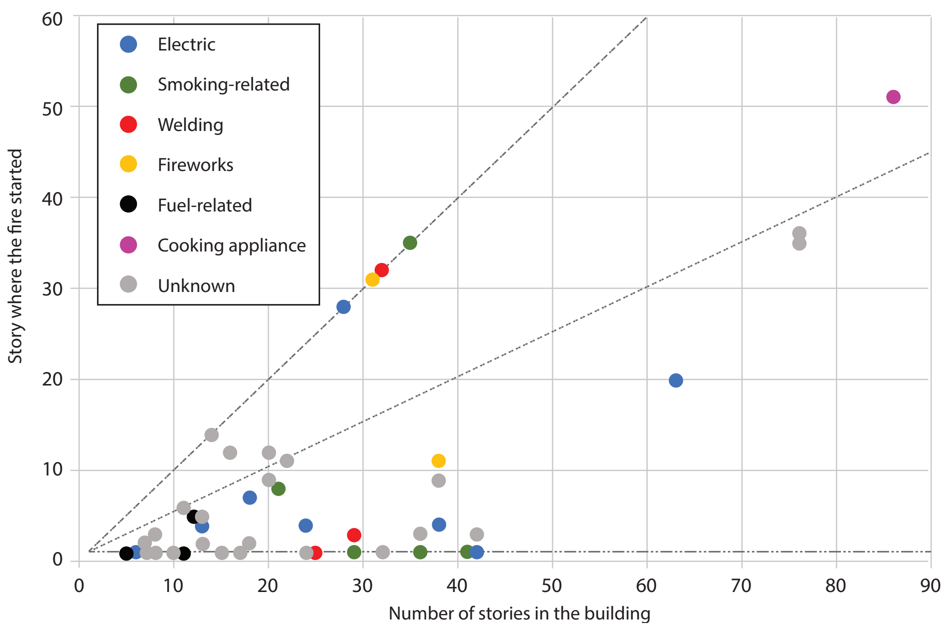

Figure 2. Cause of fire and story level where the fire was thought to have started against the number of stories in the building. The maximum possible story where a fire could have started, halfway story height and first story are indicated by the dashed lines.

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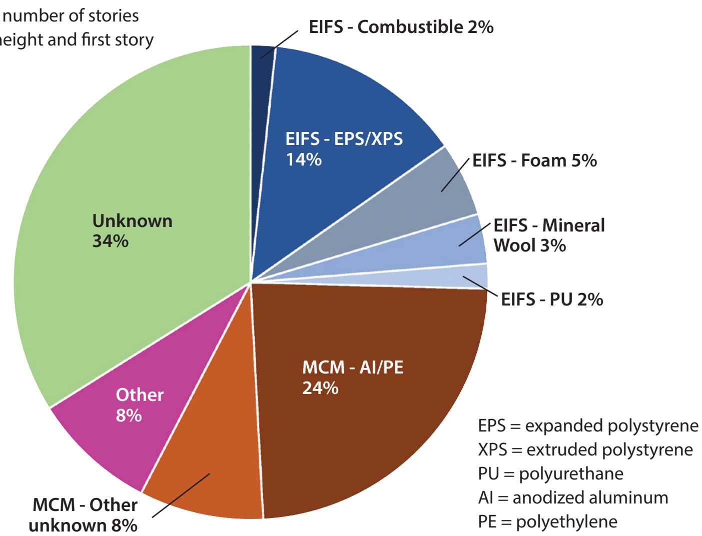

Figure 3. Façade assembly types, broken down by EIFS (exterior insulation and finish system) insulation type and MCM (metal composite material) panel product.

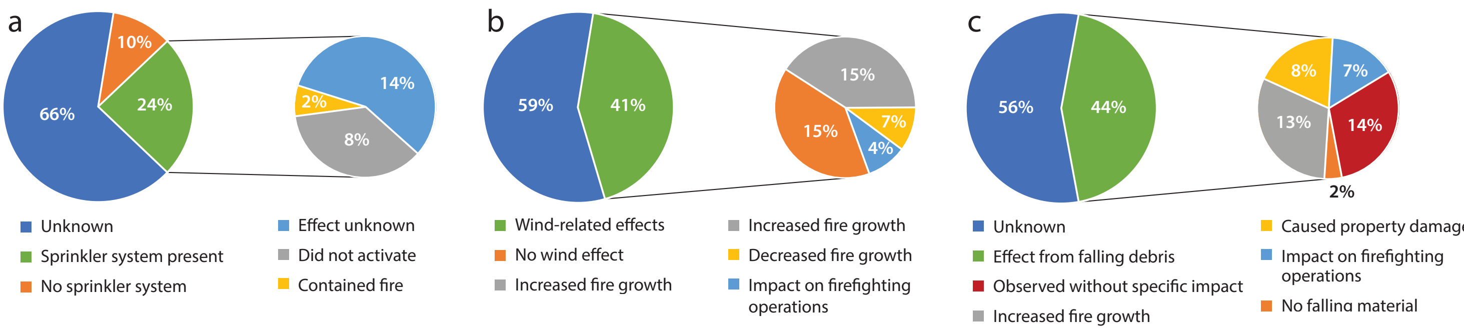

Figure 4. Proportion of fires in the database thought to have been affected by (a) sprinkler systems, (b) wind, and (c) falling debris (left circle); and the resulting effects of those factors (right circle).

In the case of falling debris, several incident reports highlight the adverse effect on firefighting operations, on the evacuation of people, the increase in fire growth due to burning material, or property damaged caused by debris. However, in some incidents, although falling debris was observed, there is no information on whether this had any impact on the fire.

Finally, several wind-related effects are identified from the data. There is the contribution to increased fire growth through fanning the flames, directing flames towards neighboring buildings, or increasing the likelihood of burning pieces of material being dislodged that may have aided in the spread of fire. However, it is noted elsewhere that the wind in some incidents likely reduced the impact of the fire by moving flames and/or smoke away from buildings. Several incident reports highlight the adverse effect of the wind on firefighting operations. For example, the wind fanned flames and carried debris to surrounding streets, whereas it was reported in another incident that the severity of the fire was reduced as the wind prevented debris, smoke, and heat from penetrating the building's interior.

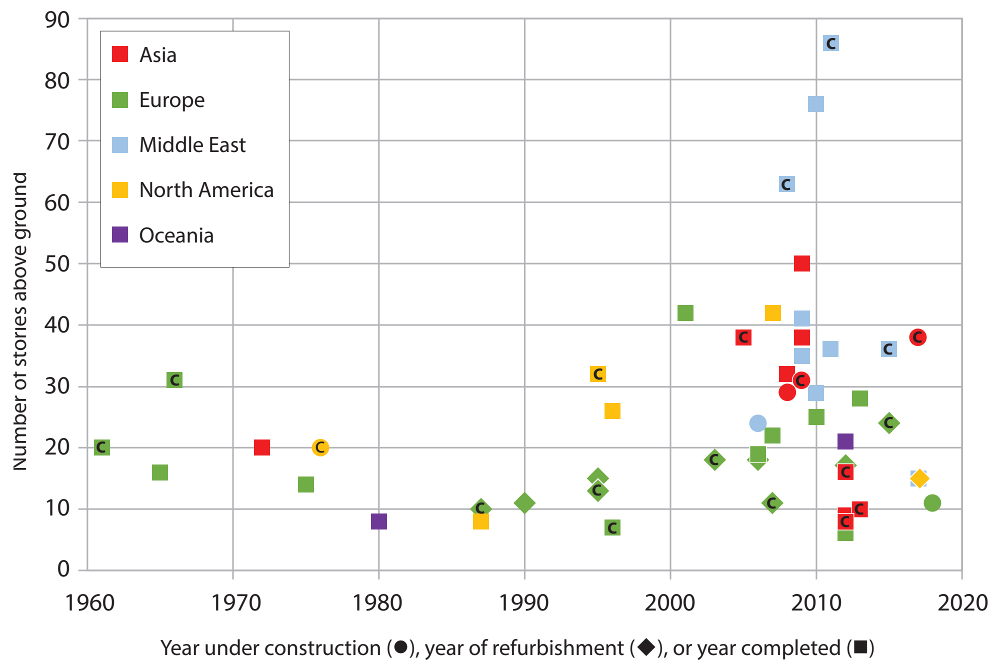

Figure 5. Façade fire incidents by year under construction / refurbishment / completed as a function of building height. "The "C" represents incidents with casualties.

Incidents Involving Casualties

A more detailed analysis was made of the database of incidents in which civilian and emergency service personnel injuries and fatalities occurred. Fires with fatalities make up 10 of the 59 incidents (17%) and those with fatalities and/or injuries make up 22 of the 59 incidents (37%). The definition and identification of injury data was subject to considerable interpretation when entering information into the database. Incidents involving injuries and fatalities involved some form of EIFS in 37% of the cases, 27% had some form of MCM assembly, 9% some other type of façade assembly, and 27% were unknown.

Combining data for the height of building; the year in which a building was under construction, completed or refurbished; the regional location of the building; and whether injuries and fatalities occurred is shown in Figure 5. Incidents in which fatalities occurred are in buildings with no more than 31 stories (generally around 100 meters). The tallest of the buildings is the 31-story, 159-meter Mandarin Oriental Hotel, Beijing, in which a single firefighter fatality was reported. Furthermore, six of the 10 incidents were in buildings of less than 14 stories. Six in 10 of the fatal fires were in buildings that had been refurbished. Injuries occurred in the tallest building, as well as those that are at the lower end of the height scale. Of the 22 incidents where casualties occurred, eight (36%) were in buildings with less than 14 stories.

As can be observed by the quantity of unknown data entries, the analysis based on the information currently publicly available is somewhat limited. It is hoped that this initial

> “The findings show that 60% of the fatality fire incidents occurred in older buildings that had undergone some form of refurbishment.”

research effort will spur other parties with pertinent, verifiable façade fire incident information to share their data and improve the quality of this database.

Machine Learning

Following the creation of the incident database, it was applied to a machine learning environment to predict some form of "severity" for a given tall building should a fire incident occur. Machine learning is an emerging field that uses neural networks and supports vector machines to systematically mine complex datasets for patterns and structures. In this work, TensorFlow has been used to train a preliminary neural network model. There are several published TensorFlow model source codes which share similarity to the problem being addressed in this study. One of them is by Google and documented as an official tutorial (Cheng et al. 2016).

The model consists of an input layer, several hidden layers (each with a number of neurons), and an output layer. The output layer of the model constructed in the study has a total of 11 severity classifications, where the severity is derived from the injury and fatality data. The classes have been broken into cases where either there were no fatalities, but zero or more injuries occurred, or where fatalities occurred. Such a method simplifies how severity is classified, but still makes it possible for the model to recognize the data patterns.

The model has been trained, using portions of the database entries, with the remaining entries held back as a test set to evaluate the model accuracy. Thus, for each training step, a different subset of database is supplied to the model via the input layer, which then flows through the hidden layers. During the process, neurons are weighted as a measure of the significance of how the preceding neurons influence the current neuron. To identify the optimal model architecture, a range of configurations for various numbers of hidden layers, neurons for each hidden layer, and training steps have been investigated. Figure 6 shows one of the trained model architectures. In this example model, four hidden layers and five neurons on each hidden layer are adopted.

Once training is complete, test incident cases are taken from the database and the model returns probabilities for each output layer class, with the class having highest probability selected as a predicted severity classification. Figure 7 shows predicted severity classification of the best-performing optimized model, evaluated on all surveyed incidents. There are four incidents where the match is poor, and several where there is some variation; in the rest, the predictions correlate to the actual incident severity.

However, the accuracy is biased, in that many of the incidents have a severity classification of zero and the model almost always predicts a zero severity as its default. This suggests that, in the future, it would be beneficial to revisit the severity classification to create one that has less bias towards a single result.

Discussion and Conclusions

The database of tall building façade fire incidents includes those fires that resulted in some significant outcome, whether casualties and/or damage to the building and neighboring property. Such incidents are often covered by media organizations. However, the level of detail and the accuracy of the reports are often lacking. The database presents a snapshot of available information, and it is likely that further existing information about incidents will come to light with more investigation, and new information will be released after the completion of the study. Therefore, it will be valuable to enhance the current database by filling in gaps, where possible.

A manual analysis of the database has identified several interesting findings

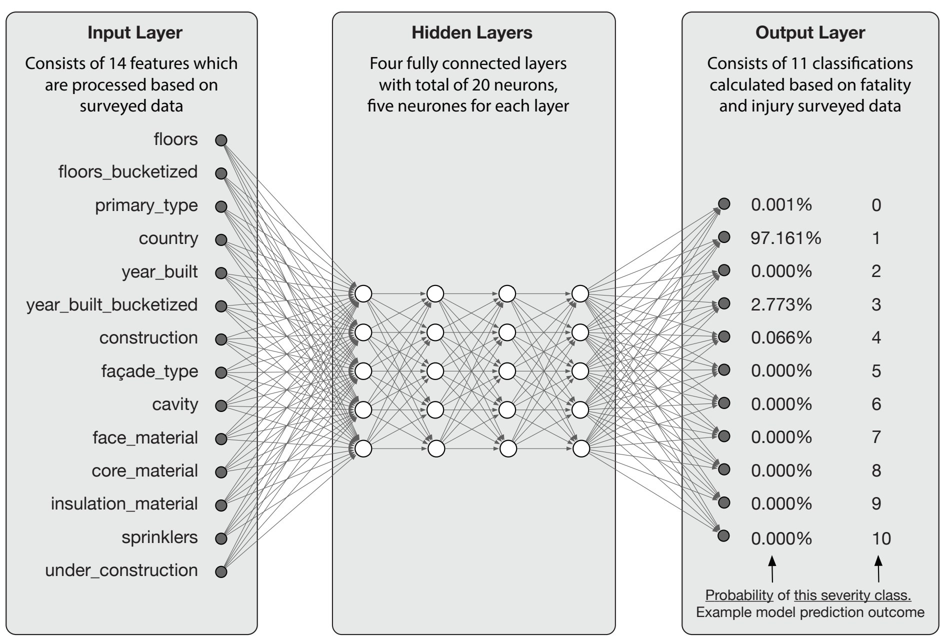

Figure 6. Example of one of the trained machine-learning models.

regarding the buildings in which incidents occurred, where casualties have resulted, the types of materials used in façade assemblies, and some tentative findings on sprinkler system performance. In summary:

- In the case of incidents involving older buildings, it is not the year of completion that is important, but that several years later these buildings underwent some form of refurbishment. Findings show that 60% of the fatality fire incidents occurred in such buildings.
- In incidents in which fatalities occurred, the buildings were less than 32 stories tall and had an EIFS-type assembly façade. When injuries are included in the analysis, then it is more difficult to identify building height and façade assembly trends in the data.
- Based on the interpretation of very limited data, the reliability of sprinkler systems in façade fire incidents is around 80%. This is within the range of 70% to 99.5% collated by Frank et al. (2013) for the effectiveness of sprinkler systems on internal building fires.

The TensorFlow machine learning software has been used to demonstrate a predictive method that relates how the type of building and façade might result in fatalities and/or injuries should a fire occur. The database has been used to create a set of input features, and a pilot severity classification has been proposed to assess the predictive capability of the machine learning environment. However, the limited scope of both the severity classification and the scarcity of available input data means results can only be taken as being indicative of the potential application of the machine learning tool.

In order to understand why tall building façade fire incidents can become major events, it would be beneficial to identify those façade-related incidents that did not significantly develop. This is a challenge, since fires that do not become major incidents do not get reported in the media, etc., to the same extent. There also needs to be a judgment made on whether the incident did involve, or had the potential to involve, the façade to a sufficient degree to be classed as a "façade fire". However, if enough of these incidents could be identified, then there is the potential to train the machine-learning system to assess the probability of a given façade installation developing into a major fire event.

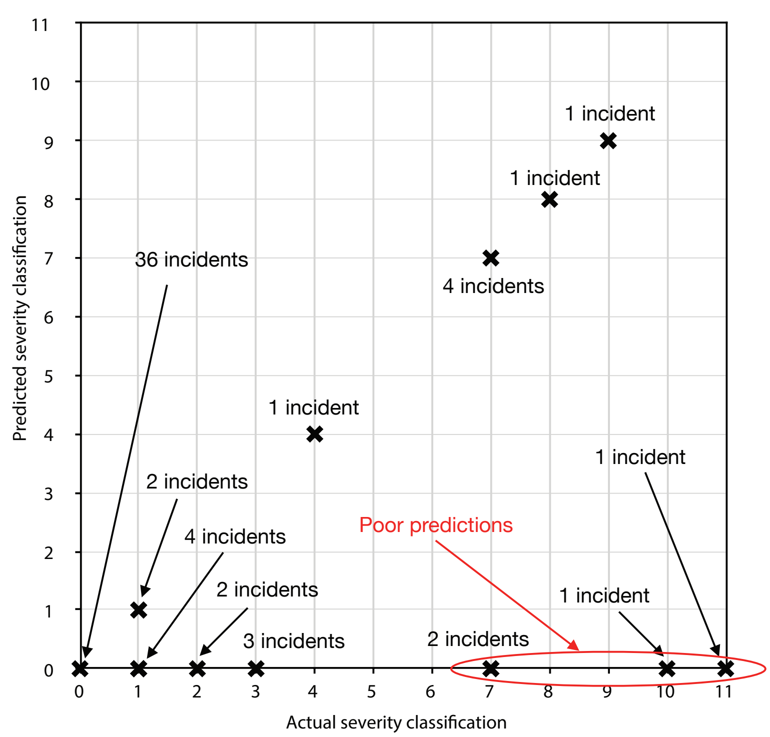

Figure 7. Modeled predictions of fire incidents and level of severity against actual incident severity.

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