Turkish Journal of Computer and Mathematics Education Vol.12 No.13 (2021), 6014-6021

Research Article

An Effective Way to Inspect the Cause of Fire at Factory and Warehouse Facilities Using the NFPA 921 Scientific Method

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Abstract: This study is to analyze the practices of fire cause inspection in the fire of factory and warehouse facilities, and suggest an effective inspection method applying the NFPA 921 scientific method. The findings of this study areas follows. First, in problem definition and data collection, if the combustion area is wide, and the process and operation method of machinery and facilities are complex, data omission can occur. Thus, this study suggests using the information system of fire-fighting organizations. Second, in data analysis and hypothesis development, as there is possibility of error in data analysis and insufficient legal objectivity in hypothesis development, this study suggests that fire inspector should secure video records along with statements of concerned persons and check manuals of machinery and facilities related with the fire. Finally, in hypothesis test and selection of the final hypothesis, this study suggests that, as the appraisal of the fire evidences can be insufficient, it is necessary for fire-fighting organization to make appraisal by itself using the equipments in the fire inspection and analysis room in the provincial and metropolitan fire departments and fire stations.

Keywords: NFPA 921, scientific method, factory, warehouse facilities, fire cause inspection

1. Preface

According to the fire statistics of the National Fire Data System, the number of fire of unknown origin in 2019 was 3,778, 9.42% out of the total 40,103 cases of fire in that year. When buildings and structures are differentiated into residential and non-residential uses, the ratios of fire of unknown origin were 9.64% and 10.79% respectively. Among the 2,412 cases of fire of unknown origin in non-residential buildings and structures, the number of factory fire of unknown origin is 333, or 14% out of 2,412 cases, that of warehouse fire of unknown origin is 218, or 16% out of 1,392 cases, and that of working place facility including car facility fire of unknown origin is 111, 16% out of 701 cases, the highest proportion in three categories.[1]

Fire inspector approaches the object on fire for the first time, and inspect the fire in overall fire-fighting process. Fire inspection starts from the awareness of fire, and proceeds to understanding of burning situation at the fire site, asking questions to the one who reported the fire and other related persons, and grasping of arrangements of the building and objects, and locations of fire-using equipments. In this process, fire inspector judges how the fire started.

In the cases of factory and warehouse fire, as economic property damages are big, related persons may have responsibility in civil and criminal laws depending on the cause of fire. Fire inspecting organizations are fire-fighting agency, the police, and insurance company, etc. Each organization has its unique view and purpose in approaching the fire case. To the police inspector, major concerns are whether the fire occurred intentionally or by mistake, and whether the criminal law can be applied to the case or not. To the insurance company inspector, material elements such as payment of fire insurance money, property damage contents, and calculation of damage amount are major targets of inspection.

As the regulation on fire inspection of fire-fighting agency, there is 'the Rule on Fire Inspection and Report' of the National Fire Agency. While the rule stipulates some basic items such as inspection principles, questions, collection of documents and information, inspection recording, and site inspection, it does not prescribe concrete inspection procedures, Fire inspector examines the cause of fire based on physical evaluation of the fire site, collection of evidence, statement of observer and related persons, general fire statistics, subjective judgement based on inspection experiences in inspecting similar fires. But, if the spot where the fire started or the heat origin of the fire cannot be presumed, or legal conflicts can be expected, fire inspector of fire-fighting agency jointly investigates with other agencies like the police or Korea Electric Safety Corporation. If the conclusions on fire origins of different

agencies conflict, the cause of fire is determined as being unknown. Fire inspector should guarantee that all the aspects in a given fire site have been explained, and apply systemic approaches and consistent methods based on scientific methods for all the things requiring better analysis and judgement.

There have been some important researches on fire inspection. **Eun-soo Son (2008)**,[2] based on literature review and a survey, extracted problems in fire inspecting system and ways to revise it. **Byeong-il Kim (2014)**,[3] based on the survey to fire-fighting officials, divided the management of fire-fighting agency into the education and training part and the organization management part, suggested an efficient way of management. **Seok-woo Choi (2016)**,[4] comparing the fire investigating systems of Korea and other countries, and offered the way to improve the Korean fire investigating system.

As a research applying NFPA 921, there is a research of **Hyeon-jeong Lee (2017)[5]**. By using the TRIZ technique in each stage of scientific fire inspection methods, Lee extracted problems in each item of the Comprehensive Report on Fire Causes composed by fire inspector of fire-fighting organization. **Gyeong-jin Park et al, (2018)[6]** used NFPA 921 to set hypotheses to reveal the cause of fire in the cold storage warehouse to which there were different opinions among inspectors. But, there was no research to prepare fire inspection procedure applying scientific method of NFPA 921 in real fire inspection.

Accordingly, the aim of this research is to analyze the practices and issues of fire inspection of fire-fighting organization in fire of factory and warehouse facilities where the cause of fire is likely to be unknown, and, by applying NFPA 921 in fire inspection stages, suggest effective fire inspection procedures.

2. NFPA 921 scientific method

2.1. The necessity to apply scientific method

NFPA 921 is the document on guidelines and recommendations for safe and systematic inspection or analysis of fire and explosion accidents issued by National Fire Protection Association (NFPA) and approved by the American National Standards Institute (ANSI). While NFPA 921 is classified not as 'standard', but as 'guide', many courts and special fire inspection institutions regard it as a kind of standard of care. Therefore, even if NFPA 921 was not intended to work as a document to establish the civil and criminal trial-related legal cases related with fire and explosion investigation, it is mentally and practically regarded as such by fire inspection specialists.[7]

Fire inspection is a comprehensive activity involving experiences, knowledge, and science. Not only collection of data, but analysis of it should be done scientifically. Scientific method is necessary for fire inspection, As it provides systemic analytic treatment procedure, it is necessary to apply this method.

2.2 Constitution of scientific method

In Figure 1, the scientific method defined by NFPA 921 is the systemic study about knowledge including recognition of the problem and systemic formulation of it. It includes collection of data through observation and experiment, analysis, setting and evaluation of hypotheses, test of theories supported by evidence, and, if possible, selection of the final hypothesis. The NFPA 921 scientific method explains the procedure as 7 stages. If a hypothesis fails to pass the test, the previous stages, hypothesis setting, collection of data, and analysis of it should be repeated to get rational findings of fire inspection.

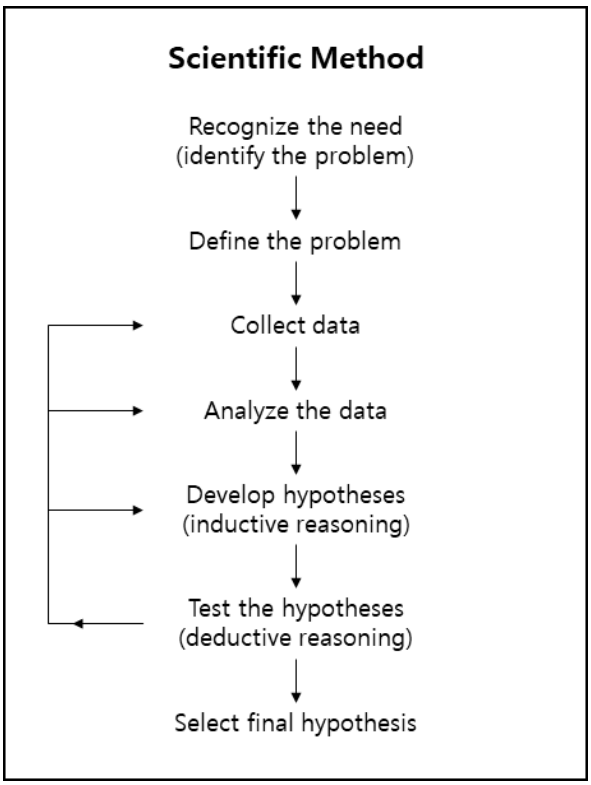

Figure 1. Scientific method of NFPA 921

'Recognize the need' is the step where inspector recognize that there is a problem to be solved. The fact that a fire occurred constitutes the recognition of the need. From the time when fire inspector goes to the fire site, he or she is given the role and responsibility for fire inspection to find out the fire origin and situation of fire.

'Define the problem' is the step where fire inspector determines what kinds of inspection are needed on fire origin and fire cause to solve the problem. This step includes determination of the method to examine fire cause and characteristics, but how to protect evidence, secure statement of observer, and selection of those who have power and responsibility.

'Collect data' is the step where fire inspector observe the fire and measure it. It includes decision of fire pattern, photo shooting, collection of physical evidence, statement of observer, and site record, etc. In addition, it includes literature review, recognition and preservation of evidence, and review and analysis of inspections of other inspectors. such data are experimental data for test, and integrity and reliability should be secured.

'Analyze the data' is the essential step to extract the final hypothesis. All the collected data should be analyzed through inductive reasoning, and someone who has knowledge, training, experience, and specialty should perform the analysis. It is subjective analytic method. Fire inspector determines based on knowledge accumulated in previous analyses of fire, education training, and understanding of fire dynamics, and learning from other inspectors, etc. Evaluation data include the degree of fire damage, direction of heat and flame, arc mapping, fire engineering, and modeling analytic tools, etc.

'Develop hypotheses' is the step where fire inspector sets hypotheses, tentative conclusions, based on physical evidence collected from the fire site and evidence of observers about fire-starting spot, fire origin, fire cause, the relation of fire origin and the first object which set fire. Hypothesis development is the efforts to get answers to the questions in scientific method. There can be a single or multiple hypotheses. If the hypothesis cannot be tested with collected data, it is useless.

'Test the hypotheses' is the step where hypotheses are examined by experiments or data. The test is done by inductive reasoning based on well-known facts. Tested hypothesis should be supported by facts. If it is not, the fire inspector should return to previous steps, and repeat the process.

'Select final hypotheses' is the final step of scientific method, which is realized only if previous steps were performed carefully and completely. If all the other hypotheses are tested in reliable levels and rejected, the remaininghypothesis can be accepted as the final hypothesis. The adopted final hypothesis should be supported

independently by evidence, and correspond to the facts. And, like other evidences, it should be strictly tested. The above descriptions can be summarized as Table 1.

Table 1. Constitution of scientific method

Classification	Definition
Recognize the need	Recognize that there are problems to solve
Define the problem	Determine how to solve the problems
Collect data	Collect real data based on observation, measurement, or sensual experiences
Analyze the data	Evaluate the relationship and meanings of collected data based not on assumptions, but on educational training, experiences, and professional knowledge, and scientific principles
Develope hypotheses	Develop tentative conclusions where collected physical evidences, evidences of observers are not contradictory in explaining fire sites, based on data
Test the hypotheses	Experiment physically or evaluate cognitively or analytically evidences to test hypotheses based on inductive reasoning
Select final hypotheses	If other hypotheses are rejected by tests, and a single hypothesis matches the facts and is reliable, adopt it as official conclusion or opinion

3. Practices of inspection of fire causes on factory and warehouse facilities

3.1. Definition of problem, data collection: Omission of collecting fire evidences

According to fire statistics of the Korean Fire Insurance Association, the most frequently cited cause of factory fire is mechanical ones like overheating and overload, and the places where fire occurs most frequently are the facility storage place and manufacturing process facilities.[8] In addition, the Fire Situation of Major Fire-Starting Place of Industrial Facilities in the 2019 Fire Statistics of the National Fire Data System also shows that the most frequent fore-starting spots of factory are facilities and storage places, different from the case of other facilities.[9] It means that fire of factory and warehouse commonly starts at the fixed facilities, that is, machine and equipment. However, if we hurriedly conclude about the causes of fire from the above statistics, the possibility of fire starting in other areas. In addition, if the destructed area caused by fire is large, and the process and operation methods of machinery and equipments are complex, it is likely that fire inspector subjectively examines a part of the area without checking all the evidence related with fire starting, and omit them in collecting data.

3.2. Data analysis, hypothesis development: Error in data analysis and lack of legal objectivity in developing hypotheses

While it is essential for fire inspector to have interview with those related with the fire, it is difficult to get complete statement from them because of their despair, embarrassment, and psychological anxiety about the possibility of recovery from the fire. Plus, it is more difficult because of their worries about the fire investigation of the police, and possibility of failing to getting compensation from the insurance company.[10] Property damage amount of the fire of factory and warehouse can be big, and diverse interests can be involved in the fire. If the related person does not actively cooperate with fire inspector, or pinpoint a specific cause of fire to get compensation from insurance company, fire inspector can be misguided to make errors in collecting data at fire site.[11]

In addition, fire inspector is burdened to prove the facts correctly, because the findings of the fire inspection can play the role of evidence in judicial judgement related with the Product Liability Act and the Law Concerning civil Liability from Fire. Consequently, in the cases where there are acute conflicts of interests or legal problems, or where ignition in the production facilities is suspected, fire inspector cannot be sure of the hypothesis unless scientific evidence supports it, and rules that the cause of the fire is not known.

3.3. Hypothesis test, selection of the final hypothesis: Insufficient examination of fire evidence

In general, while factory or warehouse fire is inspected by various organizations, fire evidences are collected by the police, and examined by National Forensic Service. The police tend to easily determine the cause of fire unless there is something which makes one to be suspicious of crime, and National Forensic Service is passive in trying to approach substantive truth about the cause of fire unless there is something which makes one to be suspicious of crime.[12] Forensic Safety Appraisal of National Forensic Service only examines specific oddity such as remains of electric short-circuit, but does not suggest ignition possibility which can occur by combining with other elements. In most cases, fire inspection of fire-fighting organization is questions to related persons and site scanning, and rarely extends to examination of the cause of fire.[13] The opinion of fire inspector on the cause of fire leads to selection of untested hypothesis, reducing the reliability of the findings of fire inspection.

4. An effective inspection method on fire of factory and warehouse facilities

The Implement Rules of the Fire-fighting Basic Law classifies fire inspection into two kinds: fire origin inspection and fire damage inspection, and specifically designate the scope of inspection. In the fire origin inspection, ignition origin is the process the fire started, the spot where the fire started and the material which set the fire. The ignition spot is the area where the fire started, and the physical location where the fire started with the contact of fire source and the combustible. In general, if the ignition spot cannot be identifiable, it is also impossible to identify the cause of fire. Thus, to inspect fire origin, the ignition spot should be determined. To determine the ignition spot, we need to combine all the information gathered from information from witnesses, fire pattern, arc matching, and fire dynamics. According to the rules, fire inspection should begin as soon as we recognize the fire. Therefore, the first step of scientific method, 'recognize the need' is made at the time when the 119 Comprehensive Situation Room receives the call of fire, and issues the order to dispatch the fire inspector to the fire site. Accordingly, the procedure of fire origin inspection following the step of recognize the need' is as follows.

4.1. Definition of problem, collection of data: Use of the information system of the fire-fighting organization

To minimize the omission of information in collecting data, we use the information system of the fire-fighting organization. Automatic Vehicle Location (AVL) and the Site Control Terminal provide the contingent and the site commander with the report content of the fire site and locational information, and they can search for the information about related fire-fighting objects by contacting the civil appeal information system. Before starting data collection, fire inspector needs to identify the situation and use of factory or warehouse facilities, and drawing information per floor before the fire occurred, which can help him to establish the plan to inspect the fire, and determine the scope of inspection.

Problem definition is to identify the origin and characteristics of fire, and the data is empirical data based on observation and experiences, and does not mean only material evidences. Through problem definition, fire inspector determines inspection scope and method. Data collection is mainly made by records of the answers to questions, taking photos, and sketches. To specify the ignition spot, such a problem definition and data collection should be made in advance, and the detailed procedure is as follows.

First, to define the problem, one needs to make the initial site evaluation. Factory and warehouse facilities can have more elements which can endanger the safety of inspector than common residential house. Therefore, it is necessary to make the initial site evaluation, first of all. Together with problem definition, site evaluation is the beginning step of data collection. Through site evaluation, inspector determines equipments necessary to fight the fire, inspection scope, inspection method, and the area necessary to do additional inspection. In this step, fire inspector should identify the fire site and surrounding areas, and secure statements of related persons.

Second, to collect data, he inspects the outside and inside of the structure. In general, the damage area of factory and warehouse fire is likely to be wide, and, frequently, the structure itself is damaged. Fire inspector should walk around the structure to identify the location and degree of damage, and evaluate the size of the site and complexity of it. He also needs to identify construction method and use of the structure, and examine construction materials, facade, the factors which can spread the fire. Inside the structure, he should examine the damage caused by fire, smoke, heat, and flame exit situation. He should take photos about all the contents of the data, and record odd elements.

4.2. Data analysis, hypothesis development: Securing of manuals for video recording equipment, machinery and facilities

To analyze data and develop hypotheses, fire inspector, first, check whether CCTVs are installed inside and outside of the structure, and secure video records. Plus, he needs to take photos about damage conditions of machinery and facilities and the assumed ignition spot, and identify the model names of machinery and check the operation methods supplied by the manufacturers of them.

Unlike the case of data collection, data analysis is made based on knowledge, training, and experiences. Statements of related persons should be recorded. With legal evidence capacity, but lacking physical evidence, they should not be used as preconditions for data analysis and hypothesis development. Only based on physical evidences identified in the fire site, inspector should analyze the data. Based on the data identified at the site and his knowledge and experiences, he develops hypotheses to assume the ignition spot. The procedure to objectively analyze data and develop hypotheses is as follows.

First, to analyze data, fire inspector inspect burning conditions of the building structure, machinery, and facilities. During inspection, he should keep in mind that the movement of objects and destruction of structure by fire-fighters, and identify transformation of inner structure and fire patterns generated by ventilation elements. If there is statements of related persons, fire inspector should check whether damages of machinery and facilities are consistent with the statements. Considering additional data accumulated in the inspection process, along with fire patterns, fire inspector should expect the potential ignition spot.

Second, based on data analysis, fire inspector develops the initial hypotheses to explain the fire growth at the presumed ignition spot. In developing hypotheses, fire inspector should consider statements of related persons, initial site evaluation, and all the data collected and analyzed in the structure inspection, and identify whether there was ignition source at the ignition spot. In this step, fire inspector should not inspect parts of the evidences to prove the initial hypotheses, but the parts which might be related with other possibilities.

Third, with repated persons attending, fire inspector excavates and recover the tentatively determined ignition spot. In this case, all the processes of excavation and recovery should be meticulously taken photos, and recorded. Collection of physical evidences which need appraisal should be made with specific evidence collecting equipment to maintain and preserve the evidence capacity of evidences, by getting approval of concerned persons. Collectors of evidences, the data of collecting them, and situations should be recorded. Even if the police judges that they are not related with a crime, evidences should be collected to test hypotheses.

4.3. Hypothesis test, selection of the final hypothesis: Inner appraisal through fire inspection and analysis room

While there can be some variations in the situation of equipments in fire departments in metropolitan cities and provinces, fire inspection and analysis room of fire department possess the equipment to investigate and appraise fire. If you suspect that there may have been another ignition source, you can appraise it internally without referring to other agency to ask for appraisal.

To satisfy the requirements of the scientific method, the hypotheses set at the fire site should be tested by inductive reasoning method. If you set multiple hypotheses, you should test and reject all of them. If a hypothesis fails to pass the test, it is necessary for fire inspector to go back to previous steps in the scientific method such as additional data collection, data analysis, and hypothesis development. The procedure of testing hypotheses and selecting final hypothesis is as follows.

First, to test hypotheses, you need to reclassify evidences collected at the site according to the hypotheses, and determine the appraisal method referring to literature or research papers. In this step, if collected data and evidences are not consistent with the statement of concerned persons, you should identify the truthfulness of statements by asking concerned persons and getting statements, and record the contents in the question record.

Second, fire inspector makes appraisal of reclassified physical evidences. In principle, fire inspector at the fire department appraises evidences using the equipment in the fire inspection and analysis room of fire station or fire department, but, if it cannot appraise them by itself, it should refer to the National fire Research Institute for appraisal. If all the hypotheses are rejected, fire inspector should repeat the previous steps, and consider re-inspection of fire site.

Third, If other hypotheses are rejected based on the appraisal of evidences, and there is the only hypothesis accepted, it is chosen as the final one. The comprehensive report on the fire should attach the logic of approaching data analysis and appraisal results of tested evidences, and describe ignition spot and ignition cause separately. NFPA 921 recommends that, if there is the only hypothesis which is not fully supported by the evidences, but is the only possible cause, fire inspector should accept it not as unknown cause, but as inconclusive cause.

5. Conclusion

This study is to analyze the situations of fire cause inspection of fire-fighting organization on factory and warehouse facilities, and by dividing fire inspection process into three steps - data collection, evaluation and analysis of data, and writing of report - to suggest an objective and systemic approach and an effective way to inspect fire causes by applying the NFPA 921 scientific method. Research findings are as follows.

First, If one reaches the definition of the problem on ignition cause hurriedly based on statistics on machinery and facilities, one can ignore other causes of ignition, and if the combustion area is wide, and the facility process and operation process are complex, data about collection of evidences can be omitted. To prevent such an omission of data, this study suggested the inner information system within fire-fighting department. Such informations can be helpful in determining establishement of the plan to inspect fire and inspection scope at the fire site.

Second, In data analysis and the process of hypothesis development, the statement of concerned persons can be erroneous. They can be psychologically not very normal, and they can conceal a fact due to complex interests involved in the fire. In such a case, data can be distorted. In addition, fire inspector is burdened to prove correct facts related with the Product Liability Act and law on the responsibility for accidental fire. To prevent such an error in data analysis, and to secure legal objectivity in developing hypotheses, this study suggested to secure video record equipments of the fire site and checking the manuals on machinery and facilities related with the fire.

Finally, in hypothesis test and selection of the final hypothesis, the evidences on fire of factory and warehouse facilities care in general collected by the police, and appraised by National Forensic Service. In most cases, fire inspection of fire-fighting organization is to ask questions to concerned persons and investigation of the fire site. Accordingly, this study suggested that it is necessary for fire-fighting organization to do appraisal of fire evidences by itself using the equipments of the fire inspection and analysis room of fire department of metropolitan and provincial fire departments and fire stations. If it is impossible, one should refer to the National fire Research Institute.

The findings of this study can be applied as the procedure of basic fire cause inspection not only to the inspection of fire cause of factory and warehouse, but to the fire of other facilities of a certain scale.

In the future, if the Law on Fire Inspection initiated by a member of the National Assembly passes it, there should be researches on rights, work scope, and specialization of fire education for fire inspectors.

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