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Evaluating and selecting data center fire protection system with analytical hierarchy process

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ABSTRACT

Fire protection systems are critical in protecting data center assets. This paper applies analytical hierarchy process (AHP) for evaluation and selection of a fire protection system for a data center. Expert opinions from multiple data center professionals were used to select the most favorable fire protection system. The selection alternatives were chosen from options that are accepted by the Life Safety Code of the National Fire Protection Association (NFPA). Results show that pre-action water sprinkler system is the preferred fire protection system. This study provides insights for data center managers in constructing new data centers or renovating of existing ones.

KEYWORDS: Fire protection system, Analytical hierarchy process, Pre-action water sprinkler system

INTRODUCTION

As our dependence on computer systems continue to grow, the challenge of maximizing data center availability and efficiency is becoming more important. Data centers and server rooms are the core of a company's business, because the servers within data centers are keeping all the company's information, records and data. This makes fire protection systems very important in shielding data centers and sustaining business continuity (Siemens 2015). According to a study conducted by Emerson (2016), data centers loose an average of $8,851 per minute when unplanned outages occur. Since data centers are extremely critical for maintaining business operations, it is important that data center owners and developers have sufficient tools for selecting the most suitable system to protect their data center.

With the high use of electrical energy within data centers, fires are very probably to start and result in costly outages. Due to the high risk, the National Fire Protection Association (NFPA) developed the NFPA 75, which is the standard for the Fire Protection of Information Technology Equipment. The Authority Having Jurisdiction (AHJ), along within the NFPA outlines the operational requirements of fire protection systems. While majority of data centers need to have fire protection systems to meet local code requirements, many data center owners opt to use gaseous total flooding systems. Although these systems are effective fire fighters, the maintenance requirements of gaseous total flooding systems can be expensive and tedious. For instance, all extinguishing agent cylinders need to be hydrostatically tested once they exceed 10 years (Chivers 2004).

It is widely believed that water based fire protection systems are risky and could easily cause damage to expensive information technology equipment. However, with increased room size the amount of gaseous agent required to totally engulf the room increases. This increase comes hand in hand with cost increases. It is understandable that data center decision makers often select gaseous agents because it does not cause potential damage to information technology equipment as water based agents would. Water based sprinkler systems can cause extensive damage to information technology equipment if a discharge of water occurs during a fire alarm.

On the other hand, when gaseous agents are released there is a considerable amount of air uproar and a thick fog that is released within the space. Gaseous agent releases can impact workers by reducing their visibility, causing disorientation, headaches and shortness of breath (Menkus 2004). Since gaseous agents extinguish fires by eliminating oxygen, there are positives and negatives to using them.

There is a shortage of data related to fire protection options that are appropriate for the data center industry. This could be due to the fact that the data center sector is not very widespread. However, data center managers need adequate tools to effectively consider all fire protection options that are available. The purpose of this study is to provide data center decision makers with information and tools to assist during the fire protection selection process. The aim is geared towards providing increased efficiency while maintaining effectiveness. Through analytic hierarchy process a structured organization of relevant decision criteria along with possible fire protection alternatives can be compared in a pairwise manner (Saaty 1980). Through this method, all factors can be considered and the most suitable fire protection system can be selected.

LITERATURE REVIEW

Extensive fire protection research has not yet been done within the data center facilities industry. There have been numerous studies that investigated fire protection systems in commercial buildings, residential homes and medical facilities. Vaidogas & Šakėnaitė (2010) used multi-attribute decision-making technique to compare the alternative fire safety designs within buildings. This study focused on general buildings; however, data centers have special requirements and other aspects to consider. Levinson on the other hand, did specialized study, which involved using Monte Carlo simulation modules to create different scenarios within nuclear plants (Levinson and Yeater 1983). Based on how the fire system performed within the simulation, the effectiveness of each fire protection system could be evaluated. Levinson approach is creative and would definitely be a method that could be considered for exploration within a data center environment.

Buildings generally use passive and active fire protection (Ismail et al. 2014). Passive fire protection involves having the building designed in compartments and using fire rated doors to prevent the spread of fires (Fadzil 1998). These passive options help to contain fires and make it easier for a fireman to control and extinguish fires (Landucci et al. 2009). Active fire protection includes building systems that will detect fires, help to get occupants to safety and work towards suppressing the fire. Ismail et al conducted a study that reviewed passive and active fire protection systems in residential apartments; however, this study will assess fire protection systems that are more applicable to equipment and computer rooms. Standard fire protection methods are not suitable for data centers due to the cost of downtime, the high heat density and the amount of electrical power within data centers.

There are three main types of fire detection devices. These devices are smoke detectors, flame detectors and heat detectors. Since smoke detectors are more sensitive to the presence of a fire, they are regarded as the preferred fire detection devices for data centers. Heat and flame detectors are generally used in harsh areas or where high temperatures are generally expected such as kitchens and plants. Smoke detectors also have multiple categories, which includes spot type smoke detection, intelligent spot-type very early smoke detection (Hu and Chen 2007), air sampling smoke detection and linear thermal detection (Avelar 2011).

Among the main types of fire suppression systems are fire extinguishers, water sprinkler systems, water mist systems, total flooding systems, foam and dry chemicals. Dry chemical extinguishing agents are fairly environmentally friendly and a good substitute for Halon extinguishing agents, which is dangerous to the environment (Su et al. 2001; Chen et al. 2015).

Although dry chemical extinguishing agents are good at putting out fires, they require excessive effort to clean up after being used (Avelar 2011). Due to the amount of clean effort required and the residue left after a discharge, dry chemicals are generally not recommended for use within data centers. Similarly, foam extinguishers are not recommended within data centers due to the conductive nature of the foam. Conductive foam posses a major problem around electrical equipment as it can cause short-circuiting, thus introducing increased risk.

Water mist systems release small water droplets onto the fire when the system goes into an alarm state. Firstly, the small water droplets extinguish the fire by lowering the temperature of the fire (Liu & Kim 1999). Secondly, the water vapor prevents the flame from getting access to oxygen, which is needed to sustain the flame (Liu et al. 2007). Studies have shown that water mist is very effective extinguisher for multiple types of fires especially in the presence of electrical equipment (Jones & Nolan 1995). Water mist systems are also good replacements for Halon systems (Mawhinney 1996).

A portable fire extinguisher is an effective way of extinguishing a fire when the fire is small. Fire extinguisher allows us to contain a fire before the fire escalates and triggers the main fire alarm system. Portable fire extinguishers are available in many options including clean agents, which are considered to be ideal for data centers (Avelar 2011). Although portable fire extinguishers are effective in fighting small fires, an automated fire suppression system is a standard requirement based on NFPA 75, which is the standard for fire protection of information technology equipment (NFPA 2013).

Water sprinkler systems discharge water to extinguish a fire typically when the sprinkler head reaches a temperature of 165 to 175 degrees Fahrenheit. Water sprinkler systems are available in three options, namely, wet-pipe, dry-pipe and pre-action (Avelar 2011). In wet-pipe systems the sprinkler pipe is normally filled with water. This makes wet-pipe systems more applicable in areas that will not freeze and will not result in a huge financial impact if there is an accidental pipe leak (Hauptmanns et al. 2008). Dry-pipe systems are generally used in areas that could freeze, such as loading docks (Li & Chow 2005). With dry-pipe systems, the pipe is normally filled with compressed air or nitrogen, in the event of a fire, water will displace the gas (air or nitrogen). Pre-action systems are somewhat similar to dry-pipe systems because the sprinkler pipe is not normally filled with water. Pre-action systems require a combination of fire detection sensors to be triggered before it will allow the sprinkler pipe to be filled with water. Even after a combination of sensors have triggered the sprinkler pipe to be filled, the heat threshold of the sprinkler head must be met before water is released to extinguish the fire (Artim 1999). Those safety guards make pre-action systems more resistant to accidental water discharge, thus making it applicable within data centers.

Fires within buildings can be suppressed by totally flooding the space with inert gases or clean agents (NFPA 2001). A total-flooding system reduces the oxygen concentration within the space and gets rid of the fire (Sass-Kortsak et al. 1987). Siemens (2015) stated that automated dry extinguishing systems (inert gas or clean agent) provide the best protection for sensitive and expensive electronic equipment within server rooms. Reimer & Shefter (1994) also mentioned that water based fire protection systems can cause more damage to the material than it protects, by resulting in financial loss and downtime. This may be true in terms of protection for the equipment. However, automated dry extinguishing systems tend to cause frequent accidental gas releases resulting in all equipment being powered off, loss of an expensive extinguishing agent and the risk of suffocating people who are present during the agent release. Clean agent systems typically need to detect a fire on two separate detectors to trigger a fire alarm and release the agent (Carter 2012). Although this reduces the probability of an accidental fire alarm, the risk still exists especially when people are working within the data center.

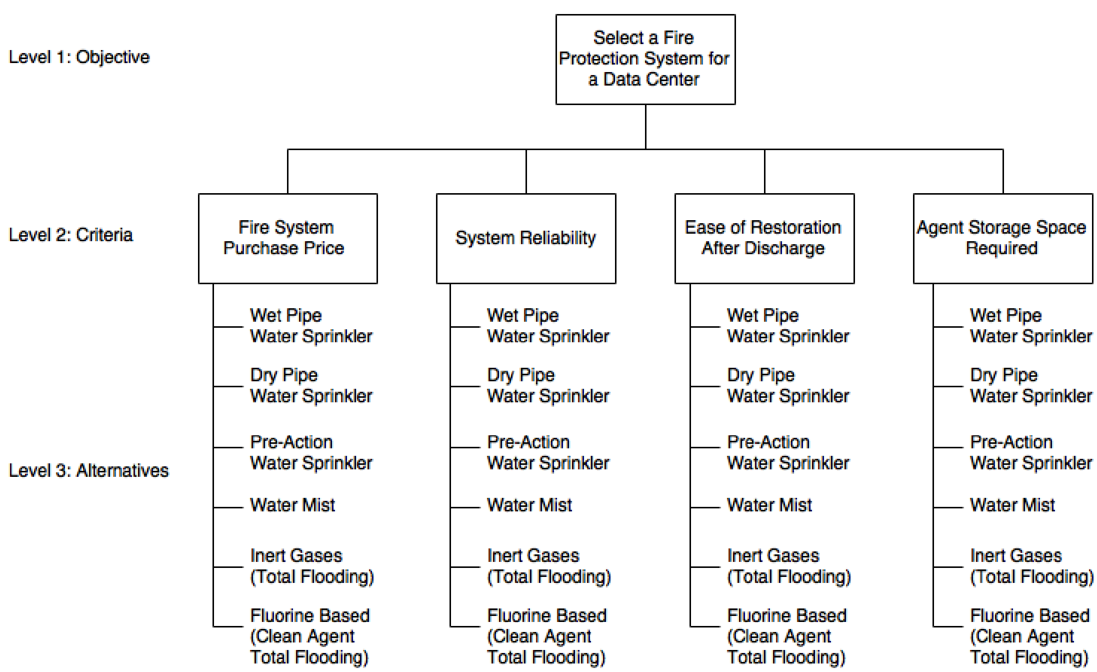
RESEARCH METHODOLOGY

This study involved the processing of data gathered from 34 professionals who work within the data center design or operations industry. A Google form was used to develop a questionnaire consisting of 11 questions for the survey to be conducted. The link for the Google form questionnaire was sent to 42 individuals via email of which 34 persons responded. Majority of the questions were Likert based with a scale of 1 to 9. The remaining questions had a mixture of closed and open-ended questions. All the information gathered from the 34 respondents was used to carry out the data analysis.
From the review of literature, criteria and alternatives were decided for the AHP model (Saaty 1980). Descriptive analysis of the responses received from the survey was used to determine the weight of each criterion within the AHP model. The Delphi method was used with 3 data center experts (Linstone & Turoff 1975). By collating the decisions of the 3 data center experts, the relative importance of each criterion and alternative was determined. The information collected was used to make pair-wise comparisons between the alternatives for each criterion to determine their weights. The pairwise comparison matrix was then transformed into a prioritization matrix using the Eigen vector, and then the weights were combined to determine the value for each option. The final values were integrated into the AHP model to determine which fire suppression alternative was the most suitable for a new data center design. To reduce bias and ensure reliability, a consistency check was carried out.

RESULTS

The AHP model was developed with the objective being to select the most suitable fire protection system for a data center. Amongst the selection criteria were Fire System Purchase Price, System Reliability, Ease of Restoration after Discharge and Agent Storage Space Required. The fire protection alternatives included Wet Pipe Water Sprinkler, Dry Pipe Water Sprinkler, Pre-Action Water Sprinkler, Water Mist, Inert Gases Total Flooding and Fluorine Based Total Flooding. This AHP model is shown within Figure 1.

Figure 1: AHP Hierarchy Diagram for Data Center Fire Protection Selection



The quantitative results obtained from the questionnaires were tabulated and summarized as shown within table 1. The variable represents the survey question. Each quantitative question had nine answer options, of which only one could be chosen. The mean of the responses for each question was used to estimate the final average response. This average response was used to determine the relative importance of each criterion, for a pairwise comparison to be carried out as shown in Table 3.

Table 1: Summary of results of obtained from survey

Variable	N	Percent	Mean	SE Mean	StDev	Minimum	Median	Average Response
When selecting a fire protection system, please select the importance level of the fire system's purchase price when compared to the system's reliability?	34	100	6.765	0.169	0.987	5	7	Reliability is definitely more important than purchase price
When selecting a fire protection system, please select the importance level of the fire system's purchase price when compared to the ease of restoration after a discharge?	34	100	7.971	0.186	1.087	5	8	Ease of restoration after a discharge is much more important than purchase price
When selecting a fire protection system, please select the importance level of the fire system's purchase price when compared to the agent storage space required?	34	100	4.647	0.133	0.774	3	5	Purchase price is of equal importance as agent storage space
When selecting a fire protection system, please select the importance level of the fire system's reliability when compared to the ease of restoration after a discharge?	34	100	3.824	0.334	1.946	1	3.5	Reliability is somewhat more important than ease of restoration after a discharge
When selecting a fire protection system, please select the importance level of the fire system's reliability when compared to the agent storage space required?	34	100	1.353	0.0832	0.485	1	1	Reliability is very much more important than agent storage space required
When selecting a fire protection system, please select the importance level of the fire system's ease of restoration after a discharge when compared to the agent storage space required?	34	100	1.706	0.166	0.97	1	1	Ease of restoration after a discharge is much more important than agent storage space required

Table 2: Relative Importance (Saaty 1980)

Relative Importance	Value
Equal importance/quality	1
Somewhat more important/better	3
Definitely more important/better	5
Much more important/better	7
Very much more important/better	9

In Table 3, when the comparison between the alternatives within the row is less than the criterion within the column, then the reciprocal of the relative importance value is used. For example, ease of restoration after discharge is much more important than purchase price so that is rated at a 7. On the other hand, comparing price to ease of restoration after a discharge the reciprocal is used thus 1/7, which is equal to 0.14.

Table 3: Pairwise comparison amongst each criterion

Criteria	Purchase Price	Ease of Restoration After Discharge	Agent Storage Space Required	Reliability
Purchase Price	1.00	0.14	1.00	0.20
Ease of Restoration After Discharge	7.00	1.00	7.00	0.33
Agent Storage Space Required	1.00	0.14	1.00	0.11
Reliability	5.00	3.00	9.00	1.00
Total	14.00	4.29	18.00	1.64

Using the Delphi technique, three experienced experts within the data center facilities industry were interviewed (Linstone & Turoff 1975). The experts assisted with conducting pairwise comparisons amongst the fire protection alternatives as related to each criterion. Through the Delphi technique the feedback from the experts was used to populate the pairwise comparison matrix shown within Table 4.

After the pairwise comparisons were done, the priority vector was found each criterion and alternative. By taking the average of row, each criterion and alternative is normalized to form a priority vector. This priority vector represents weighting given to each criterion and alternative. Since the pairwise comparison matrix can be inconsistent, a consistency check was carried out for the pairwise comparisons.

In carrying out the consistency check, the product matrix is computed by multiplying the pairwise comparisons by their respective priority vector. The ratio matrix is then computed by dividing the respective product value its respective priority vector (Saaty 1980). Furthermore, the average of these ratios is calculated. For example, the calculation for Table 6 is shown below:

Averaged Ratio (AR)-

$$\frac{\frac{0.283}{0.07}+\frac{1.404}{0.33}+\frac{0.235}{0.06}+\frac{2.400}{0.54}}{4} = 4.203$$

Consistency Index (CI) : $CI = \frac{(AR)-n}{n-1}$ (1)

Where n is the number of comparisons, in this case n is equal to 4 because there are four criteria being compared with Table 6.

Table 4: Pairwise comparison of amongst alternatives and each criterion

	Alternatives	Wet Pipe Water Sprinkler	Dry Pipe Water Sprinkler	Pre-Action Water Sprinkler	Water Mist	Inert Gases Total Flooding	Fluorine Based Total Flooding
Purchase Price	Wet Pipe Water Sprinkler	1.00	2.00	5.00	6.00	7.00	9.00
	Dry Pipe Water Sprinkler	0.50	1.00	3.00	5.00	6.00	8.00
	Pre-Action Water Sprinkler	0.20	0.33	1.00	2.00	5.00	6.00
	Water Mist	0.17	0.20	0.50	1.00	1.00	2.00
	Inert Gases Total Flooding	0.14	0.17	0.20	1.00	1.00	2.00
	Fluorine Based Total Flooding	0.11	0.13	0.17	0.50	0.50	1.00
	Total	2.12	3.83	9.87	15.50	20.50	28.00
Ease of Restoration After Discharge	Wet Pipe Water Sprinkler	1.00	1.00	1.00	0.20	0.17	0.14
	Dry Pipe Water Sprinkler	1.00	1.00	1.00	0.20	0.17	0.14
	Pre-Action Water Sprinkler	1.00	1.00	1.00	0.20	0.17	0.14
	Water Mist	5.00	5.00	5.00	1.00	0.33	0.25
	Inert Gases Total Flooding	6.00	6.00	6.00	3.00	1.00	0.50
	Fluorine Based Total Flooding	7.00	7.00	7.00	4.00	2.00	1.00
	Total	21.00	21.00	21.00	8.60	3.83	2.18
Agent Storage Space Required	Wet Pipe Water Sprinkler	1.00	1.00	1.00	3.00	7.00	6.00
	Dry Pipe Water Sprinkler	1.00	1.00	1.00	3.00	7.00	6.00
	Pre-Action Water Sprinkler	1.00	1.00	1.00	3.00	7.00	6.00
	Water Mist	0.33	0.33	0.33	1.00	5.00	4.00
	Inert Gases Total Flooding	0.14	0.14	0.14	0.20	1.00	0.50
	Fluorine Based Total Flooding	0.17	0.17	0.17	0.25	2.00	1.00
	Total	3.64	3.64	3.64	10.45	29.00	23.50
Reliability	Wet Pipe Water Sprinkler	1.00	0.50	0.13	0.20	0.20	0.20
	Dry Pipe Water Sprinkler	2.00	1.00	0.17	0.25	0.25	0.25
	Pre-Action Water Sprinkler	8.00	6.00	1.00	4.00	7.00	7.00
	Water Mist	5.00	4.00	0.25	1.00	3.00	3.00
	Inert Gases Total Flooding	5.00	4.00	0.14	0.33	1.00	1.00
	Fluorine Based Total Flooding	5.00	4.00	0.14	0.33	1.00	1.00
	Total	26.00	19.50	1.83	6.12	12.45	12.45

$$CI = \frac{(4.203) - 4}{4 - 1} = 0.068$$

Finally, the Consistency Ratio (CR) is computed using:

$$CR = \frac{CI}{RI} \quad (2)$$

From Saaty's table of random consistency index provided, RI is equal to 0.90 since n is equal to 4. Therefore, equation 2 can be used to calculate CR as shown below:

$$CR = \frac{CI}{RI} = \frac{0.058}{0.90} = 0.075$$

According to Saaty, if CR < 0.1, then the degree of consistency is satisfactory (Saaty 1980). Since this value was deemed to be consistent, there is no need to revise the pairwise comparison values. In this particular case, CR = 0.075 < 0.1, thus consistency was achieved. The same consistency calculation procedure was repeated to conduct consistency verifications for the weight of alternatives on each criterion. The resulting values are displayed within Table 6.

Table 5: Consistency check for weights of criteria

	Purchase Price	Ease of Restoration After Discharge	Agent Storage Space Required	Reliability	Priority Vector	Product	Ratio	CI	CI/RI
Purchase Price	0.07	0.03	0.06	0.12	0.07	0.28	4.02	0.07	0.08
Ease of Restoration After Discharge	0.50	0.23	0.39	0.20	0.33	1.40	4.24		
Agent Storage Space Required	0.07	0.03	0.06	0.07	0.06	0.23	4.12		
Reliability	0.36	0.70	0.50	0.61	0.54	2.40	4.43		

Table 6: Consistency check for the weight of alternatives on each criterion

	Alternative	Wet Pipe Water Sprinkler	Dry Pipe Water Sprinkler	Pre-Action Water Sprinkler	Water Mist	Inert Gases Total Flooding	Fluorine Based Total Flooding	Priority Vector	Product	Ratio	CI	CI/RI
Purchase Price	Wet Pipe Water Sprinkler	0.47	0.52	0.51	0.39	0.34	0.32	0.43	2.74	6.45	0.04	0.04
	Dry Pipe Water Sprinkler	0.24	0.26	0.30	0.32	0.29	0.29	0.28	1.81	6.39		
	Pre-Action Water Sprinkler	0.09	0.09	0.10	0.13	0.24	0.21	0.15	0.90	6.24		
	Water Mist	0.08	0.05	0.05	0.06	0.05	0.07	0.06	0.38	6.20		
	Inert Gases Total Flooding	0.07	0.04	0.02	0.06	0.05	0.07	0.05	0.32	5.99		
	Fluorine Based Total Flooding	0.05	0.03	0.02	0.03	0.02	0.04	0.03	0.20	6.06		
Ease of Restoration After Discharge	Wet Pipe Water Sprinkler	0.05	0.05	0.05	0.02	0.04	0.07	0.05	0.28	6.05	0.04	0.03
	Dry Pipe Water Sprinkler	0.05	0.05	0.05	0.02	0.04	0.07	0.05	0.28	6.05		
	Pre-Action Water Sprinkler	0.05	0.05	0.05	0.02	0.04	0.07	0.05	0.28	6.05		
	Water Mist	0.24	0.24	0.24	0.12	0.09	0.11	0.17	1.06	6.14		
	Inert Gases Total Flooding	0.29	0.29	0.29	0.35	0.26	0.23	0.28	1.83	6.47		
	Fluorine Based Total Flooding	0.33	0.33	0.33	0.47	0.52	0.46	0.41	2.62	6.44		
Agent Storage Space Required	Wet Pipe Water Sprinkler	0.27	0.27	0.27	0.29	0.24	0.26	0.27	1.66	6.19	0.02	0.02
	Dry Pipe Water Sprinkler	0.27	0.27	0.27	0.29	0.24	0.26	0.27	1.66	6.19		
	Pre-Action Water Sprinkler	0.27	0.27	0.27	0.29	0.24	0.26	0.27	1.66	6.19		
	Water Mist	0.09	0.09	0.09	0.10	0.17	0.17	0.12	0.73	6.14		
	Inert Gases Total Flooding	0.04	0.04	0.04	0.02	0.03	0.02	0.03	0.19	6.03		
	Fluorine Based Total Flooding	0.05	0.05	0.05	0.02	0.07	0.04	0.05	0.27	6.01		
Reliability	Wet Pipe Water Sprinkler	0.04	0.03	0.07	0.03	0.02	0.02	0.03	0.20	6.22	0.10	0.08
	Dry Pipe Water Sprinkler	0.08	0.05	0.09	0.04	0.02	0.02	0.05	0.30	6.08		
	Pre-Action Water Sprinkler	0.31	0.31	0.55	0.65	0.56	0.56	0.49	3.45	7.04		
	Water Mist	0.19	0.21	0.14	0.16	0.24	0.24	0.20	1.37	6.99		
	Inert Gases Total Flooding	0.19	0.21	0.08	0.05	0.08	0.08	0.12	0.73	6.35		
	Fluorine Based Total Flooding	0.19	0.21	0.08	0.05	0.08	0.08	0.12	0.73	6.35		

In order to arrive at the weighting for each alternative, both priority vector matrices criteria and criteria with alternatives were multiplied. In other words, the priority vectors with Tables 5 and 6 were multiplied to arrive at the total scores, which are shown in Table 7.

Table 7: Overall rating of each fire protection system from AHP

Alternatives	Total Scores
Wet Pipe Water Sprinkler	0.078
Dry Pipe Water Sprinkler	0.078
Pre-Action Water Sprinkler	0.306
Water Mist	0.174
Inert Gases Total Flooding	0.162
Fluorine Based Total Flooding	0.202

The survey candidates were asked to choose which of the six fire protection options would be their first choice for use within a data center. This question was an attempt to capture whether the results from AHP coincided with the unscientific decision of the respondents. Table 8 shows the percentage of respondents that choose each alternative.

Table 8: Opinionated response for the best fire protection system

Which of the six fire protection systems would be your first choice for use within a data center:	
Alternatives	Response Percentage
Wet Pipe Water Sprinkler	0%
Dry Pipe Water Sprinkler	3%
Pre-Action Water Sprinkler	29%
Water Mist	9%
Inert Gases Total Flooding	18%
Fluorine Based Total Flooding	41%

DISCUSSION

The Google form survey was distributed to a variety of data center professionals. This research involved 34 samples of which 24, 29, 21 and 26 percent had 1 to 3, 3 to 7, 7 to 10 and over 10 years of experience within the data center industry respectively. Response bias corrections were attempted through conducting consistency checks. All the consistency ratios were less than 0.1, thus it was concluded that pairwise comparisons for criteria and alternatives with criteria were all reliable.

The results from the analytical hierarchy process indicate that purchase price of the fire system represents only 7% of the final decision. Ease of restoration after a discharge represented 33% of the final decision. The storage space that extinguishing agent requires accounted for only 6% of the final decision. Overall, the most important criterion was found to be the reliability of the system, which accounted for 54% of the final decision. Thus, reliability is definitely the most dominant measure when selecting a data center fire protection system.

Through Analytical Hierarchy Process a final weight was derived for each alternative fire protection option. From Table 7, the optimum fire protection option for a data center was the pre-action water sprinkler system. The pre-action water sprinkler system accounted for 30.6% of the total scores. Other scores included fluorine-based total flooding which had a score of 20.2%, water mist with 17.4% and inert gases total flooding with 16.2%. Both wet-pipe and dry-pipe water sprinkler systems had a score of 7.8%. The first choice alternative that was selected by the respondents was slightly different from the results produced by AHP. From the opinionated selection shown in Table 8, we have fluorine based total flooding as the preferred alternative with a 41% selection. Pre-action water sprinkler was the second favorite with a 29% selection. This shows that the results from AHP’s pairwise comparisons may result in a different outcome from random decision. The opinionated response appears to consider the ease of restoration criterion only, since fluorine based total flooding was the strongest within that criterion. The results from Table 8 confirms the problem statement that water based sprinkler systems are generally not preferred by data center professionals.

As it relates to strengths and weakness, the priority vector within Table 6 indicates how well each alternative ranked amongst each criterion. Wet pipe water sprinkler was the best with regards to purchase price (0.425). With ease of restoration (0.408) after discharge, fluorine based total flooding was ranked the highest. Wet-pipe, dry-pipe and pre-action water sprinkler systems were highest ranked with the agent storage space required (0.268) criterion. Pre-action water sprinkler was ranked the highest in regards to reliability (0.490). With weaknesses, fluorine based total flooding was the lowest ranking in terms of purchase price (0.032). All three water sprinkler systems were ranked the lowest on ease of restoration after discharge (0.046). Inert gases total flooding was the lowest ranked based on the agent storage space required (0.032) criterion. Wet-pipe water sprinkler was the lowest ranked in the area of reliability (0.033).

The scare that a number of the respondents had with water sprinkler systems was the risk of an accidental alarm that causes a flood and damages information technology equipment. Although pre-action water sprinkler systems have multiple safeguards to prevent accidental water discharge, there are also opportunities to improve fire prevention within data centers through implementation of best practices. Some of these best practices may include, ensuring that all openings within room walls are resealed with fire retardant. Ensuring that no trash or combustible material such as cardboard or paper is stored within the data center is also helpful. If paper needs to be stored within the data center, then it should be stored with a closed metal enclosure. Other options include installing sprinkler heads that are recessed within the ceiling and installing a very early smoke detection apparatus system may also be very useful for addressing potential fires before they manifest.
Threats to data center fire protection could include bad electrical installations that lead to fires. Bad electrical installations could come from making loose connections and overfilling conduits or cable trays. A threat also exists if the computer room air conditioning units are not conditioning the heat exhausted from servers. Overall, human error is a still a leading cause of fires, therefore, attention should be placed on adequately training data staff of the best practices related to data center operations.

CONCLUSION

Through the use of AHP and thorough pairwise comparisons the most suitable data center fire protection system can be selected. The study concludes that pre-action water sprinkler system is the preferred fire protection system for data centers. Stakeholders do not want to use a system that will trigger an accidental agent release or a system that will not successfully suppress a fire. The AHP model created within this study can act as a tool for assisting data center decision makers when deliberating on which fire protection system should be used when constructing or renovating a data center. This study revealed that reliability was the most important criteria when selecting a fire protection system for use within a data center.

APPENDIX

Survey Questionnaire:
Data Center Fire Protection System Selection

1. How long have you been working within the Data Center or Information Technology Facilities Industry?

☐1 to 3 years

☐3 to 7 years

☐7 to 10 years

☐Over 10 years

2. Please select all the types of fire protection systems that you have experience with?

☐Wet Pipe Water Sprinkler

☐Dry Pipe Water Sprinkler

☐Pre-Action Water Sprinkler

☐Water Mist

☐Inert Gases (Total Flooding)

☐Fluorine Based (Clean Agent Total Flooding)

3. Please select all the factors that you believe are important when selecting a fire protection system for a data center?

☐Fire System Purchase Price
☐System Reliability
☐Ease of Restoration After Discharge
☐Agent Storage Space Required
Other: ____________________

4. When selecting a fire protection system, please select the importance level of the fire system's purchase price when compared to the system's reliability?
☐Purchase price is very much more important
☐Purchase price is much more important
☐Purchase price is definitely more important
☐Purchase price is somewhat more important
☐Purchase price is of equal importance
☐Reliability is somewhat more important
☐Reliability is definitely more important
☐Reliability is much more important
☐Reliability is very much more important

5. When selecting a fire protection system, please select the importance level of the fire system's purchase price when compared to the ease of restoration after a discharge?
☐Purchase price is very much more important
☐Purchase price is much more important
☐Purchase price is definitely more important
☐Purchase price is somewhat more important
☐Purchase price is of equal importance
☐Ease of restoration after a discharge is somewhat more important
☐Ease of restoration after a discharge is definitely more important
☐Ease of restoration after a discharge is much more important
☐Ease of restoration after a discharge is very much more important

6. When selecting a fire protection system, please select the importance level of the fire system's purchase price when compared to the agent storage space required?
☐Purchase price is very much more important
☐Purchase price is much more important
☐Purchase price is definitely more important
☐Purchase price is somewhat more important
☐Purchase price is of equal importance
☐Agent storage space required is somewhat more important
☐Agent storage space required is definitely more important
☐Agent storage space required is much more important
☐Agent storage space required is very much more important

7. When selecting a fire protection system, please select the importance level of the fire system's reliability when compared to the ease of restoration after a discharge?

☐Reliability is very much more important
☐Reliability is much more important
☐Reliability is definitely more important
☐Reliability is somewhat more important
☐Reliability is of equal importance
☐Ease of restoration after a discharge is somewhat more important
☐Ease of restoration after a discharge is definitely more important
☐Ease of restoration after a discharge is much more important
☐Ease of restoration after a discharge is very much more important

8. When selecting a fire protection system, please select the importance level of the fire system's reliability when compared to the agent storage space required?
☐Reliability is very much more important
☐Reliability is much more important
☐Reliability is definitely more important
☐Reliability is somewhat more important
☐Reliability is of equal importance
☐Agent storage space required is somewhat more important
☐Agent storage space required is definitely more important
☐Agent storage space required is much more important
☐Agent storage space required is very much more important

9. When selecting a fire protection system, please select the importance level of the fire system's ease of restoration after a discharge when compared to the agent storage space required?
☐Ease of restoration after a discharge is very much more important
☐Ease of restoration after a discharge is much more important
☐Ease of restoration after a discharge is definitely more important
☐Ease of restoration after a discharge is somewhat more important
☐Ease of restoration after a discharge is of equal importance
☐Agent storage space required is somewhat more important
☐Agent storage space required is definitely more important
☐Agent storage space required is much more important
☐Agent storage space required is very much more important

10. Which of the six fire protection systems would be your first choice for use within a data center?
☐Wet Pipe Water Sprinkler
☐Dry Pipe Water Sprinkler
☐Pre-Action Water Sprinkler
☐Water Mist
☐Inert Gases (Total Flooding)
☐Fluorine Based (Clean Agent Total Flooding)

11. What was the main reason for selecting the fire protection option chosen above?

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