Application of Deep Learning: A Review for Firefighting

Dr Muhammad Khalid Shaikh

Department of Computer Science, Federal Urdu University of Arts, Science & Technology, Karachi, Pakistan

Summary
The aim of this paper is to investigate the prevalence of Deep Learning in the literature on Fire & Rescue Service. It is found that deep learning techniques are only beginning to benefit the firefighters. The popular areas where deep learning techniques are making an impact are situational awareness, decision making, mental stress, injuries, well-being of the firefighter such as his sudden fall, inability to move and breathlessness, path planning by the firefighters while getting to an fire scene, wayfinding, tracking firefighters, firefighter physical fitness, employment, prediction of firefighter intervention, firefighter operations such as object recognition in smoky areas, firefighter efficacy, smart firefighting using edge computing, firefighting in teams, and firefighter clothing and safety. The techniques that were found applied in firefighting were Deep learning, Traditional K-Means clustering with engineered time and frequency domain features, Convolutional autoencoders, Long Short-Term Memory (LSTM), Deep Neural Networks, Simulation, VR, ANN, Deep Q Learning, Deep learning based on conditional generative adversarial networks, Decision Trees, Kalman Filters, Computational models, Partial Least Squares, Logistic Regression, Random Forest, Edge computing, C5 Decision Tree, Restricted Boltzmann Machine, Reinforcement Learning, and Recurrent LSTM. The literature review is centered on Firefighters/firemen not involved in wildland fires. The focus was also not on the fire itself. It must also be noted that several deep learning techniques such as CNN were mostly used in fire behavior, fire imaging and identification as well. Those papers that deal with fire behavior were also not part of this literature review.

Keywords:
Deep Learning, Firefighting, Literature Review, Structural Fires

1. Introduction

Firefighters risk their lives every day to keep a city and its resident safe in the time of several emergencies ranging from small fires to large scale structural fires. Developed countries pay more attention to the safety and well-being of the firefighters due to the availability of funds and resources; however same is not the case when it comes to under-developed countries. The economic situation in under-developed countries do not allow dedicated investment in any sector except for food and border security. It is the responsibility of the researchers from under-developed countries as well to develop whatever is possible for these firefighters in their research labs, which can ease the job of saving lives for the firemen. This review of literature is conducted to enable the researchers from the under-developed countries to identify the areas in which other researchers around the world are working when it comes to the use of Deep Learning. This review of literature can not only provide a chance to the researchers to further the work of others in the areas identified here, but also focus on those areas that were not been the focus of others. Although deep learning is not a new area of research however it has experienced a sudden growth recently, because of the use of GPU and deeply layered neural networks in data analysis. Moreover, the availability of large amounts of data now has also fed this growth. Today, a large number of architectures and algorithms are available for deep learning ranging from recurrent neural networks (RNNs), convolutional neural networks, to self-organizing map (SOM), restricted Boltzman machine (RBM) and autoencoders (AE). The focus of this research would be to identify how these algorithms and architectures have been helpful for the firemen as individuals.

2. Method of Research

The author has worked with the Fire & Rescue Service of the UK, in the past; this has provided this research a predisposition that it would drift into those areas that may not be related to an individual fireman. Such as, the focus of this research is strictly restricted to those research articles that had used deep learning techniques only to impact and support a firefighter, and has deliberately ignored other areas such as how fire behaves, operation reporting techniques, acquisition of resources for the fire brigade, etc. The databases such as EBSCO, Web of Science and Microsoft Academic and Google Scholar were searched for the last ten years (2010-2020). The keywords used for the identification of research articles were: (firefighter, structural fire, firemen) AND (Deep Learning, K-Means clustering, CNN, LSTM, PCA, Deep Neural Networks, Simulation, Virtual Reality, Q Learning, Decision Trees, Kalman Filters, Random Forest, Edge Computing, Restricted Boltzmann Machine, Reinforcement Learning). DistillerSR is used in order to eliminate the duplicates. Later, the articles were screened and reviewed. Once the articles were selected, data was extracted from each article to ensure accuracy and consistency in interpretation. Total identified articles were

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45 in number; however, since many of them were in the area of wildland fire, therefore such research articles were removed leaving only those papers in the database that were about the firefighters working in structural fires.

Table 1: Deep Learning in Firefighting

Which aspect of an individual Firefighter is investigated	Deep Learning Technique used	Ref.
Situation Awareness, Decision-making	Deep learning	[1]
Situational awareness, Decision-making	Convolutional Neural Networks	[2]
Firefighter Mental Stress	Traditional K-Means clustering with engineered time and frequency domain features, convolutional autoencoders and long short-term memory (LSTM) autoencoders	[3]
Firefighter injuries	Principle Component Analysis, Deep Neural Networks	[4]
Classification of Firefighter stress	Simulation, VR	[5]
Situation Awareness	Machine learning, Convolutional Neural Networks, ANN, Deep-Q	[6]
Occluded object reconstruction for firefighters	Deep learning based on conditional generative adversarial networks	[7]
Recognizing any emergency occurring to a firefighter	Decision Trees	[8]
Path planning for Firefighters	Deep Q-learning	[9]
Wayfinding for the Firefighters	Convolutional Neural Networks	[10]
Thermal Imagery in Smoke filled environment where firefighters are present.	Deep Neural Network	[11]
Tracking Firefighter while in operation	LSTM, Kalman filters	[12]
Situational awareness	Virtual reality and computational models	[13]
Navigation of people such as firefighters	Convolutional Neural Networks	[14]
Firefighter's physical fitness	Partial Least Squares, Machine Learning	[15]
Firefighting operation	Machine Learning	[16]
Firefighter decision-making	Logistic Regression, Decision Tree and Random Forest.	[17]
Firefighter stress level	Machine Learning	[18]
Firefighter exertion	Machine Learning	[19]
Firefighter employment	Machine Learning	[20]
FF response efficiency	Machine Learning	[21]
Smart firefighting in all domain	Edge computing	[22]
Firefighter Stress	Machine Learning, C5 Decision Tree	[23]
Firefighter breath and oxygen saturation	Restricted Boltzmann Machine	[24]
Firefighter intervention prediction	Variable Selection Technique	[25]
Firefighting group/team	Reinforcement Learning	[26]
Number and nature of Firefighting operation for acquiring right firefighters	Machine learning process based on anonymized data	[27]
Firefighter interventions	Recurrent LSTM	[28]
Firemen prediction	Neural Network	[29]
Firefighter clothing and safety	Artificial Neural Networks	[30]
Firefighter operation	Deep Learning using CNN	[31]

2. Results

The papers that were finally accepted for this literature review are enlisted in the following table 1 given below. The table presents the aspects related to an individual firefighter in which deep learning techniques are applied, the deep learning techniques used, and the problem statement of the research. The results have shown that researchers were interested in the following areas: deep learning techniques are making an impact are situational awareness, decision making, mental stress, injuries, well-being of the firefighter such as his sudden fall, inability to move and breathlessness, path planning by the firefighters while getting to an fire scene, wayfinding, tracking firefighters, firefighter physical fitness, employment, prediction of firefighter intervention, firefighter operations such as object recognition in smoky areas, firefighter efficacy, smart firefighting using edge computing, firefighting in teams, and firefighter clothing and safety. Moreover, the techniques that were found popular among researchers were Deep learning, Convolutional autoencoders, Long Short-Term Memory (LSTM), Traditional K-Means clustering with engineered time and frequency domain features,Principle Component Analysis, Deep Neural Networks, Simulation, VR, ANN, Deep Q Learning, Decision Trees,Deep learning based on conditional generative adversarial networks, Kalman Filters, Computational models, Partial Least Squares, Random Forest, Logistic Regression,Edge computing, C5 Decision Tree, Restricted Boltzmann Machine, Reinforcement Learning, and Recurrent LSTM. The review shows that there is no one very popular technique of deep learning that is routinely applied to the firefighters research. The Gated Recurrent Unit technique is found not used in the literature on individual firefighter; similarly, the techniques such as self-organizing maps, restricted Boltzmann machines, autoencoders, deep Q learning were only seldom used in the reviewed literature.

Table 2: Deep Learning Techniques In Firefighting

Deep Learning Technique	Frequency
Artificial Neural Network	2
Anonymized Data (with Machine Learning)	1
C5 Decision Tree	1

Convolutional Neural Network	5
Convolutional Autoencoders	1
Decision Tree	3
Deep Learning	1
Deep learning (conditional generative adversarial networks)	1
Deep Neural Networks	2
Deep Q Learning	1
Edge Computing	1
Kalman Filter	1
Logistic Regression	1
LSTM	4
Machine Learning	8
Principle Component Analysis	1
Random Forest	1
Recurrent LSTM	1
Reinforcement Learning	1
Restricted Boltzman Machine	1
Simulation	1
Traditional K-Means clustering	1
Variable Selection Technique	1
VR/AR	3

The factors in which the deep learning techniques were applied in order to facilitate a firefighter in structural fires were diverse however they were not exhaustive. It is found that the researchers had worked on improving the situational awareness of the firefighters. Situation awareness plays an important role in any type of emergency decision making. It is the "awareness of environment, the understanding of their meaning, and the projection of theirfuture status" [32]. Machine learning, Convolutional Neural Networks, ANN, Deep-Q are used to create an automated system for object detection in real-time and recognition utilizing recent data to achieve improved situational awareness of firefighters on the scene. The other concept that is discussed with respect to deep learning is the decision making of firefighters. Firefighters and other emergency managers makes decisions under time stress. They have to make decisions quickly and they should be effective too. Decision making process is a main stay topic in firemen research and several decision making processes such as Shaikh [33] and Klein [34] are available in the literature that are related specific to this area. However, deep learning is now starting to facilitate the decision making process of firefighters using its capability of using available information in a more effective manner [such as 1, 2]. Mental stress is an already defined hazard of jobs such as firefighting. Deep learning is used to study the mental stress among firefighters using various unsupervised methods based on unlabeled heart rate variability (HRV) data; stress is also measured through the innovative devices such as tele-monitoring wearable systems [3]. Stress is also studied using scaleable systems for apprehendingunswerving data about stress based on Internet of Things (IoT) and VII using simulation and virtual reality [5]. It can also be concluded from the literature review that heart rate variation is effectively used for gauging stress in firefighters. Therefore, machine learning researchers were also interested in building datasets to train an implementable stress-detector, for which "labeled HRV data in controlled environments, where subjects were exposed to physical, psychological and combined stress. This data is then enacted with machine learning and C5 decision tree to separate and identify the different stress types and understand the relationship with HRV data" [23]. Deep learning is also studied in terms of firefighter injuries. Researchers have used PCA and deep neural networks to explore the noticeable causes that affect firefighter injuries [4]. About firefighter tracking for various purposes such as injuries or their well-being, researches are conducted using deep learning to recognize human activity in emergencies using a helmet mounted with IMU and time-of-fly laser distance sensor using sensor fusion method [8]. Deep learning based on "conditional generative adversarial network is also used for occluded object detection using augmented reality" [7]. Deep learning based on conditional generative adversarial networks is used "to train relations between the numerousimageries of flammable and hazardous objects and their partially occluded counterparts" [7]. Literature has also shown that a Deep Q-learning based agent is developed who is resistant to stress induced stupefaction and anxiety; it helps in clear decisions for course-plotting based on the observed and stored facts in real fire environments. Convolutional Neural Networks is used for virtual wayfinding experiment so as to simulate the human response when subjects are memorizing or recalling different wayfinding information.Deep Neural Network model is also proposed in the literature for thermal-inertial odometry (DeepTIO) by incorporating a visual hallucination network to provide the thermal network with complementary information. For tracking the firefighters, LSTM andKalman filters are used. Through deep learning, researchers have obtained a way to accurately identify firefighter through zero-velocity-aided inertial navigation system (INS) by replacing the standard zero-velocity detector with a long short-term memory (LSTM) neural network [12]. Virtual reality and computational models are used for improved situational awareness using virtual and augmented reality (VR/AR) for training and equipping fire-fighters. Researchers have also integrated such systems with computing models and decision support tools to provide situation awareness and address challenges faced by firefighters on the fire ground [13]. In order to assist the firefighters in moving towards the emergency situation location, Convolutional Neural Network is used. The researchers "have proposed automated systems to detect emergency cars from CCTV footage using the deep convolutional neural network" [14]. Partial Least Squares andMachine learning system are used to identify the relationships between various physical health parameters and performance on simulated firefighting ability. Through "the use of a partial least-squares regression (PLSR) algorithm to analyze the linear correlation, researchers have shown the relationship between various training performances of specific ability tests with physical fitness

parameters" [15]. Researchers have also used Restricted Boltzmann Machine to develop unsupervised machine learning "approach to process breathing sounds to predict breathing rates and depth or length of breaths to assess the health and safety of firefighters" [24]. Researchers have also aimed at "developing distributed coordination and cooperation method based on reinforcement learning to enable team of homogeneous, autonomous fire fighter agents, with similar skills to accomplish complex task allocation, with emphasis on firefighting tasks in disaster space" [26]. Literature also shows that machine learning isused for the purpose of providing accurate results, using a learning process based on anonymized data [27]. Recurrent LSTM is used for the purpose of showing that the firefighter interventions can be predicted[28]. Moreover how many of them are required are also predicted using neural networks [29]. Artificial Neural Networks is getting used to develop individual models for predicting thermal protective and thermo-physiological comfort performances of fabrics [30]. In order to assist the firefighters in identifying the people and personnel trapped in fire, deep learning CNN is in use. Deep Learning using CNN is used as "an approach to detect people trapped in burning sites, in a manner that will ensure the safety of firefighters and accelerate the rescue process of victims" [31].

4. Discussion

This paper has identified the literature on how Deep Learning is assisting the firefighters in their operation in structural firefighting operation. It is found that the pace in the use of Deep Learning in this area is slow and the literature available is also sparse. Although areas such as firefighter's well-being during the operation, assistance in rescue operation, ability to identify occluded objects, mental stress, health, safety, their recruitment, resource allocation, personnel allocation, firefighter's clothing, operational efficiency and effectiveness, firefighter emergency decision making, physical fitness, situation awareness, ability to detect stationary firemen and victims, and path planning are covered in the literature. However not much work is reported in any of these individual areas; one may find only few references in each one of these areas. Moreover, how firefighters may be assisted as teams during firefighting, how they may communicate with the fireground commander and the role of Incident Command System in firemen's operational life is altogether missing. There is also a dearth of datasets on which one can work while doing Deep learning research. Another area that is missing in the literature is the ability to predict how soon firemen should be retired from active duty based on their past participation in fire and rescue operation. Firefighting is a very stressful job and it is not appropriate to keep sending the firefighters in a fire zone after a certain number of times he is exposed to extreme fire situations. Each extreme fire situation take a toll of the mental health of a firemen; it would be unfair and unjustified towards both the victims as well as towards the firemen to send them in another extreme fire situation after they may have faced non-recoverable mental stress; such re-emergence of similar extreme fire situation can cause hidden fears to appear in the middle of a crises situation. Another limitation in the literature is that there is no work reported from under-developed countries such as Pakistan, India, Bangladesh, although several extreme fire situations had already happened in such countries in the recent past. No data collection protocol specifically to collect data for Deep learning research is available in the literature on firefighting. Lastly, one must also note that the real advantage of Deep learning in structural fires for firefighters is so far not taken, however new techniques are quickly entering into the race, such as some work can be found on Smart Firefighting using Edge Computing.The classification presented above represents the areas in which the Deep learning literature has made an impact, albeit in a very limited manner. More research is required thus more classes should be added to this list.

Table 3: Deep Learning Techniques: Literature Classification

Classification	**Which aspect of an individual Firefighter is investigated**
Decision making	Situation Awareness, Decision-making
Firefighter Stress	Firefighter Mental Stress and its Classification
Firefighter injuries	Firefighter injuries
Firefighter Vision	Occluded object reconstruction for firefighters and Thermal Imagery in Smoke filled environment where firefighters are present.
Firefighter Operational Mortality	Recognizing any emergency occurring to a firefighter, Tracking Firefighter while in operation, Firefighter breath and oxygen saturation
Firefighter Navigation	Path planning for Firefighters and Wayfinding, and Navigation of people such as firefighters
Firefighter Physical Fitness	Firefighter's physical fitness and Firefighter exertion
Firefighter's general Firefighting Operations	Firefighting operation
Firefighter Employment	Firefighter employment
Firefighter Operational Efficiency	FF response efficiency
Edge Computing	Smart firefighting in all domain
Firefighter Intervention Prediction	Firefighter intervention prediction, Number and nature of Firefighting operation for acquiring right firefighters and Firemen prediction
Team Firefighting	Firefighting group/team
Firefighting Clothing for Safety	Firefighter clothing and safety

5. Conclusion

A review of literature on firefighters is conducted. The focus of the review is to identify those papers that were written on the application of deep learning for a firefighter in structural fires. The scope of the review does not includes the application of deep learning on fire

behavior. The focus of research also does not include wildland fires. The review found that the deep learning techniques are only starting to benefit the firefighters. There is a dearth of the use of deep learning for solving the problems of firefighters in an applied manner. Only few researches were found using a specific deep learning technique. More application research is required per deep learning technique in the field of firefighting.

References

[1]. Bhattarai, M., Jensen-Curtis, A. R., &Martínez-Ramón, M. (2020). An embedded deep learning system for augmented reality in firefighting applications. *arXiv preprint arXiv:2009.10679*.

[2]. Bhattarai, M., & Martinez-Ramon, M. (2020). A deep learning framework for detection of targets in thermal images to improve firefighting. *IEEE Access*, *8*, 88308-88321.

[3]. Oskooei, A., Chau, S. M., Weiss, J., Sridhar, A., Martínez, M. R., & Michel, B. (2021). Destress: deep learning for unsupervised identification of mental stress in firefighters from heart-rate variability (hrv) data. In *Explainable AI in Healthcare and Medicine* (pp. 93-105). Springer, Cham.

[4]. Yang, Z., & Liu, Y. (2018, July). Investigating the influential factors on firefighter injuries using statistical machine learning. In *2018 International Conference on Machine Learning and Cybernetics (ICMLC)* (Vol. 2, pp. 422-427). IEEE.

[5]. Chau, S. M. (2020). Firefighter Virtual Reality Simulation for Personalized Stress Detection. In *KI 2020: Advances in Artificial Intelligence: 43rd German Conference on AI, Bamberg, Germany, September 21-25, 2020, Proceedings* (Vol. 12325, p. 343). Springer Nature.

[6]. Bhattarai, M. (2018). End-to-End Deep Learning Systems for Scene Understanding, Path Planning and Navigation in Fire Fighter Teams.

[7]. Yun, K., Lu, T., & Chow, E. (2018, April). Occluded object reconstruction for first responders with augmented reality glasses using conditional generative adversarial networks. In *Pattern Recognition and Tracking XXIX* (Vol. 10649, p. 106490T). International Society for Optics and Photonics.

[8]. Hackett, S., Cai, Y., & Siegel, M. (2019, October). Activity Recognition from Sensor Fusion on Fireman's Helmet. In *2019 12th International Congress on Image and Signal Processing, BioMedical Engineering and Informatics (CISP-BMEI)* (pp. 1-6). IEEE.

[9]. Bhattarai, M., & Martinez-Ramon, M. (2020). A deep Q-Learning based Path Planning and Navigation System for Firefighting Environments. *arXiv preprint arXiv:2011.06450*.

[10]. Wang, Y., Shi, Y., Du, J., Lin, Y., & Wang, Q. (2020). A CNN-based personalized system for attention detection in wayfinding tasks. *Advanced Engineering Informatics*, *46*, 101180.

[11]. Saputra, M. R. U., de Gusmao, P. P., Lu, C. X., Almalioglu, Y., Rosa, S., Chen, C., ... &Trigoni, N. (2020). Deeptio: A deep thermal-inertial odometry with visual hallucination. *IEEE Robotics and Automation Letters*, *5*(2), 1672-1679.

[12]. Wagstaff, B., & Kelly, J. (2018, September). LSTM-based zero-velocity detection for robust inertial navigation. In *2018 International Conference on Indoor Positioning and Indoor Navigation (IPIN)* (pp. 1-8). IEEE.

[13]. Yang, L., Liang, Y., Wu, D., & Gault, J. (2018, October). Train and equip firefighters with cognitive virtual and augmented reality. In *2018 IEEE 4th International Conference on Collaboration and Internet Computing (CIC)* (pp. 453-459). IEEE.

[14]. Roy, S., & Rahman, M. S. (2019, February). Emergency Vehicle Detection on Heavy Traffic Road from CCTV Footage Using Deep Convolutional Neural Network. In *2019 International Conference on Electrical, Computer and Communication Engineering (ECCE)* (pp. 1-6). IEEE.

[15]. Xu, D., Song, Y., Meng, Y., István, B., &Gu, Y. (2020). Relationship between Firefighter Physical Fitness and Special Ability Performance: Predictive Research Based on Machine Learning Algorithms. *International Journal of Environmental Research and Public Health*, *17*(20), 7689.

[16]. Zohdi, T. I. (2021). A digital twin framework for machine learning optimization of aerial fire fighting and pilot safety. *Computer Methods in Applied Mechanics and Engineering*, *373*, 113446.

[17]. Teixeira, L. P. P. B. (2020). *Predictive analytics applied to firefighter response, a practical approach* (Doctoral dissertation).

[18]. Sandulescu, V., &Dobrescu, R. (2015, November). Wearable system for stress monitoring of firefighters in special missions. In *2015 E-Health and Bioengineering Conference (EHB)* (pp. 1-4). IEEE.

[19]. Kupschick, S., Pendzich, M., Gardas, D., Jürgensohn, T., Wischniewski, S., & Adolph, L. Predicting firefighters' exertion based on machine learning techniques.

[20]. HE, B., MITROVIC-MINIC, S. N. E. Z. A. N. A., GARIS, L., ROBINSON, P., & STEPHEN, T. (2019). Hiring schedule optimization at the surrey fire department.

[21]. Lian, X., Melancon, S., Presta, J. R., Reevesman, A., Spiering, B., & Woodbridge, D. (2019, August). Scalable Real-time Prediction and Analysis of San Francisco Fire Department Response Times. In *2019 IEEE SmartWorld, Ubiquitous Intelligence & Computing, Advanced & Trusted Computing, Scalable Computing & Communications, Cloud & Big Data Computing, Internet of People and Smart City Innovation (SmartWorld/SCALCOM/UIC/ATC/CBDCom/IOP/SCI)* (pp. 694-699). IEEE.

[22]. Wu, X., Dunne, R., Zhang, Q., & Shi, W. (2017, October). Edge computing enabled smart firefighting: opportunities and challenges. In *Proceedings of the Fifth ACM/IEEE Workshop on Hot Topics in Web Systems and Technologies* (pp. 1-6).

[23]. Pluntke, U., Gerke, S., Sridhar, A., Weiss, J., & Michel, B. (2019, July). Evaluation and classification of physical and psychological stress in firefighters using heart rate variability. In *2019 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)* (pp. 2207-2212). IEEE.

[24]. Hamke, E. E., Martínez-Ramón, M., Nafchi, A. R., & Jordan, R. (2019). Detecting breathing rates and depth of breath using LPCs and Restricted Boltzmann Machines. *Biomedical Signal Processing and Control*, *48*, 1-11.

[25]. Hadad, D., Al Masry, Z., Nicod, J. M., Varnier, C., &Zerhouni, N. (2019, May). A Predictive Decision Approach for Firefighters Using Variable Selection Technique. In *2019 Prognostics and System Health Management Conference (PHM-Paris)* (pp. 258-263). IEEE.

[26]. Abdolmaleki, A., Movahedi, M., Lau, N., & Reis, L. P. (2012, June). A distributed cooperative reinforcement learning method for decision making in Fire Brigade Teams. In *Robot Soccer World Cup* (pp. 237-248). Springer, Berlin, Heidelberg.

[27]. Couchot, J. F., Guyeux, C., & Royer, G. (2019, June). Anonymously forecasting the number and nature of firefighting operations. In *Proceedings of the 23rd International Database Applications & Engineering Symposium* (pp. 1-8).

[28]. Nahuis, S. L. C., Guyeux, C., Arcolezi, H. H., Couturier, R., Royer, G., &Lotufo, A. D. P. (2019, April). Long short-term memory for predicting firemen interventions. In *2019 6th International Conference on Control, Decision and Information Technologies (CoDIT)* (pp. 1132-1137). IEEE.

[29]. Guyeux, C., Nicod, J. M., Varnier, C., Al Masry, Z., Zerhouny, N., Omri, N., & Royer, G. (2019, September). Firemen prediction by using neural networks: A real case study. In *Proceedings of SAI Intelligent Systems Conference* (pp. 541-552). Springer, Cham.

[30]. Mandal, S., Annaheim, S., Greve, J., Camenzind, M., & Rossi, R. M. (2019). Modeling for predicting the thermal protective and thermo-physiological comfort performance of fabrics used in firefighters' clothing. *Textile Research Journal*, *89*(14), 2836-2849.Modeling for predicting the thermal protective and thermo-physiological comfort performance of fabrics used in firefighters' clothing

[31]. Jaradat, F., & Valles, D. (2018, December). A Human Detection Approach for Burning Building Sites Using Deep Learning Techniques. In *2018 International Conference on Computational Science and Computational Intelligence (CSCI)* (pp. 1434-1435). IEEE.

[32]. Weidinger, Julian, Sebastian Schlauderer, and Sven Overhage. "Information Technology to the Rescue? Explaining the Acceptance of Emergency Response Information Systems by Firefighters." IEEE Transactions on Engineering Management (2021).

[33]. Shaikh, Mohammad K. Cue-centric model of the fireground incident commander's decision making process. Diss. Loughborough University, 2011.

[34]. Klein, Gary A. "A recognition-primed decision (RPD) model of rapid decision making." Decision making in action: Models and methods 5.4 (1993): 138-147.

Dr. M Khalid Shaikh is working as an Assistant Professor at the Department of Computer Science, Federal Urdu University of Arts, Science& Technology Karachi. He holds a PhD in Computer Science from Pakistan, MPhil by research in Information Systems from the UK, a Master's degree in Computer Science and a second Master's degree in Statistics from Pakistan. He is also a Foundation/Practitioner certified PRINCE2 Project Manager from the UK. His areas of interest include Software Project Teams, and Data Science.