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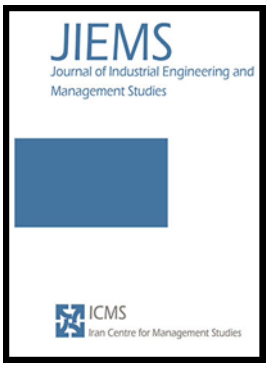

Simulation of fire stations resources considering the downtime of machines: A case study

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Abstract

Considering the increasing growth of cities, population and urban fabric density, it seems necessary that emergency facilities and services such as fire stations are positioned optimally so that they can fulfill the demands well. The aim of this study is the optimization of equipment use in the fire stations, minimization the time to arrive at the incident through management of referral call to 125 Sari fire station center so that the referral call to the nearest fire station do not remain unanswered as much as possible and there will be no need to refer to another station. In this research, the resources required at Sari's fire station were simulated using Enterprise Dynamic software. The input data of the simulation is based on the number and sequence of the time of people's phone calls. After collecting historical data from telephone calls using the function fitting method, the distribution function of available resources is calculated in Minitab software. In the following, the distribution functions of failure in the existing fire engines are calculated using the same method and the obtained information is simulated. The result indicates an improvement of 20% in relief time by adding one source in Sari fire station center.

Keywords: fire station resources; simulation of firefighting resources; downtime of machines; distribution function.

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1. Introduction

During the past 30 years the number of natural and non-natural disasters increases 6 times. In 2007, 414 disasters including Hurricane, earthquake and fire killed about 17000 people and 211 million were affected. Economic damage was estimated about 75 billion (Yao, Zhang and Murray, 2019, Ghasemi et al., 2019). Some of these statistics including fire and earthquake happened in Myanmar and china in 2008 killed more than 150000 people and more than 13 million were affected. Due to environmental transformation, increase of urbanism and fire outbreak, these statistics will be 5 times in the next 50 years (Dong et al.,

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2018). The united nation states that these statistics change each year. This general trend shows an increase in the frequency, intensity and extent of the destructiveness of the disasters (Wang et al, 2016, Tirkolaee et al., 2019). Fire is one of the oldest disasters which can put in danger people's properties and health in a short time. If fire is not controlled in a short time it may cause many damages. Sometimes fire is accompanied by other natural disasters like earthquake or happens immediately after it. In many cases, secondary fire damage is more than the first event which was the reason for the second one. According to the conducted research by firefighting department, the occurrence of various incidents in the country considering the extent, climate diversity, man-made hazards, unfair distribution of facilities and services will lead to catastrophic problems (Zhang et al. 2019, Goli et al., 2020). Lack of adequate regulations and proper implementation and effectiveness of existing safety regulations, construction of tall buildings, people's safety cultural weakness, lack of comprehensive plan of safety education for citizens, nonconformity of fire protection considerations in big urban plans, lack of legal status for firefighters, shortage of funds for construction and equipment for fire stations and improper location of fire stations are some of the important reasons for growth and increase of fire incidents in the whole country (Goli, et al., 2019). One of the ways to increase the efficiency and safety factor depends on identification, study and correct implementation of new methods of risk reduction along with the construction and equipping fire stations and correct locating (Murray, 2013). Following locating principles and the establishment of public services and urban units with the aim of maximizing their efficiency and effectiveness as well as planning and designing these units are not common. Fire stations as a place to keep ready fire trucks and relief cars are the important and vital service centers in cities (Blagojević and Pešić, 2011). Different regions of urban area and the radius of fire stations operation are major factors in planning the location of the stations. To achieve the standard, stations territory range should be reduced to 3-5 minutes, in result relief cars drive 500-670 meters per minute with the speed of 30-40 km per hour that by accounting one-minute loss to deliver fire message to station and fire trucks move from station in the 4 remained minute, fire fighters can cover a distance about 2-2/7. The area of this region will be about 12/5-23 km. (Murray, 2013). In this research, in section 3 literature review is discussed. In section 4 research method and system recognition is presented. In section 5 data collection and in section 6 the used model is presented. Sections 7, 8 and 9 investigated model output, model validity and the analyses of the proposed model. Finally, in section 10 conclusion and suggestions for future studies are presented.

2. Research Necessity

Statistics show that each year a lot of human and financial losses occur in the society due to emergency incidents (Nateghi-Alahi and Izadkhah, 2004). This will cause public concern and double the responsibility of rescue and firefighting units in reducing the consequences of incidents. The most important thing to note is reducing the response time of units. In other words, these units should be present immediately after the occurrence of incidents with adequate resources for rescue operation or fire suppression (Ghasemi et al., 2019). There are some complications in management of these units for improving response time. In this paper, it is tried to reduce the adverse consequences by providing a framework that through it the optimization of dispatch policies and better coverage of emergency events occur. These investigations and analyses about fire incidents and the performance of fire stations indicate that there are limitations and major constraints and gaps in locating and optimal performance of stations. These problems and deficiencies can be classified in the following:

- Nonconformity of location and station coverage radius with potential fire centers
- The disproportion of number of stations with the number of covered population
- A mismatch between location of stations with requirements and urban fabric

- A mismatch between location of stations with standard time coverage
- The inadequacy of the number of stations in proportion to both population and cities' area
- Impossibility to dispatch the rescue and relief team to the occurred incident to referral call from 125 command center due to lack of resources in the station

One of the best actions for prevention of fire incidents progress is adding to the number of fire stations, but due to the lack of space in the city as well as the high cost of establishment of a station, adding to the number of stations is one of the long-term projects of firefighting department. Another effective step to reduce the relief time is increasing the resources in the stations (tanker, fire extinguishers, etc.) (Yang et al., 2007).

3. Literature Review

Chen et al. (2020) tried to optimize and simulate resources and determine the facility capacity at the fire station. To do this, they considered 25 indicators and ranked them using the AHP approach. The use of fuzzy data was one of the innovations of this research. The considered case study was the fire station of Zhengzhou city. The results showed the proper performance of the proposed method. Liu et al. (2020) optimized the minimum number of fire stations to cover gas stations in a city. The results of the case study indicated that 38 fire stations are needed for 458 gas stations. Considering the traffic on the route was one of the innovations of this research. Babaee Tirkolaee et al. (2019) presented a model for municipal waste collection using the weed optimization approach. One of the innovations of this research was considering uncertainty in demand along with capacitated arc routing. The results showed the proper performance of the proposed model. Sangaiah et al. (2019) developed a mixed integer programming model to optimize resources in the liquefied natural gas supply chain. One of the innovations of the proposed model was considering the uncertainty in supply and demand. The proposed chain consisted of three levels of producer, distributor and customer. Finally, the proposed model was calculated using cuckoo optimization algorithm and robust optimization. Davoodi and Goli (2019) sought to locate distribution centers in disaster situations. Allocation of distribution centers to affected areas along with vehicle routing considering tour covering was among the innovations of this study. Finally, the proposed model was solved with hybrid Benders decomposition and variable neighborhood search. Mukherjee et al., (2019) optimized the fire station resources in China. Resources considered included fire engines and manpower. The location of the fire station was also one of the innovations of this research. The results showed the proper performance of the proposed model in Wuhan city. Kumar, Ramamritham, and Jana (2019) investigated the allocation of the fire station resources in Mumbai. Demand, travel time and radius of coverage were among the inputs of the proposed model. Resources considered included fire engines and their equipment. The results showed a 10 to 15 percent increase in the radius of coverage after model implementation. Algharib (2011) evaluated fire stations' coverage in the city of Kuwait. After evaluating the distribution of fire stations using location-allocation models in geographic information system environment, this result was obtained: some stations are outside the defined service area based on 9 minutes' standard time. He used available location-allocation models in Arc GIS software and compared these models (Algharib, 2011). Lacomme, Prins, and Ramdane-Cherif (2004) offered a mixed integer programming model for disaster relief in critical situations using fire trucks. In this model, the objective function included: Mini-Max and the minimization of the highest cost by each machine and relief time. Carter, Walker and Ignall (1973) have started optimization of inside resources in fire stations in New York. This article addresses some applications of simulation model as a tool to help decision-making about the location of fire stations in New York City. The results of simulation are used to evaluate new policies of locating, relocation and dispatching of fire units. Design related epistemology issues and models use are also discussed in this article, in addition , considering fire department response time to alarm (alarm notifications), a simulation model is provided to assess and improve the performance of these units. The main reasons of providing the model for researchers are:

1) Comparison of alternative policies and providing new solutions without human and financial loss and spending.

2) A better understanding of fire-fighting operations through clarifying the interaction between the system and the results of the proposed measures (Carter et al., 1973).

In the conducted simulation three types of policies are tested including facility distribution policy, relocation policy and resource allocation policies. Regarding the mentioned policies and statistical data, alarm in different hours of a day, the average number of calls and the type of events, various policies are presented that for each of them simulation is performed, then the simulation results are compared with the real world result. In his article Bjarnason et al. (2009) discusses optimization based on resource determination simulation and emergency response. This simulation is a magnification of Corvallis firefighting center. In this paper simulation is done through the optimization software called SOFER and backup system data are used to optimize resource location. This study combines two problems including: location of fire stations and emergency response strategy using simulation software SOFER. The locations of fire stations and the optimum number of sources are checked. It should be noted that the sources are fire engines. About the emergency response, the system investigates allocation of each resource based on the type of incident, required equipment and incident location. Considering the results of this study one of the fire stations can be closed and with the number of previous calls the desired function can be achieved. In this paper dual-model simulation algorithm is used. According to previous studies we find out that there has been no comprehensive study to optimize the resources through simulation approach in the fire stations. Also in recent studies fire machineries downtime which makes the research closer to reality has been neglected.

Thus, considering the literature review, the research gap is expressed as follows:

- Not paying attention to the simulation method and its capabilities in resource optimization
- Not paying attention to the failure of fire engines in the simulation of fire station resources
- Not paying attention to the location of fire stations considering the number of calls and the number of available resources
- Not paying attention of the previous research to the calculation of the distribution functions of "the arriving time at the incident site for each station" and "the returning time to the station".

4. Research Method

This is a functional research with an analytical descriptive nature. For data collection, documentary and field method has been adopted. In documentary method, data are collected in Sari firefighting information and statistic center. In the field method, historical data have been used for statistics and information of Sari Fire Station and the data archive from 2017 to 2018 has been collected.

4.1. System Recognition

When an incident happens, people who are present in the incident location call the fire center (125) and explain what happened. Based on the sampling carried out during one month it is observed that 5 percent of dialed calls to the fire station are nuisance calls. In half of these calls the rescue team was dispatched to the location and the other halves are detected in the emergency call and the rescue team is not dispatched. The 125 center located in Mollamajeddodin street, informs the fire stations about the incident when they are sure about the accuracy of the calls, then the relief officials are dispatched to the location from receiving stations according to the predetermined shift work and then after operation and collection of equipment leave the location and return to the station. The Firefighting Relief in Sari is composed of three 8-hour shifts. The first shift is since 8 to 16 pm, the second is since 16 to 24 and the third one from 24 to 8 am. In each shift a fire truck with a capacity of 3000 liters is serving. To avoid the complexity in the numbers of investigable parameters (e. g type of car, the type of operation team, type of incident location), each station is considered as a separate unit. Firefighting process diagram is shown in figure 1.

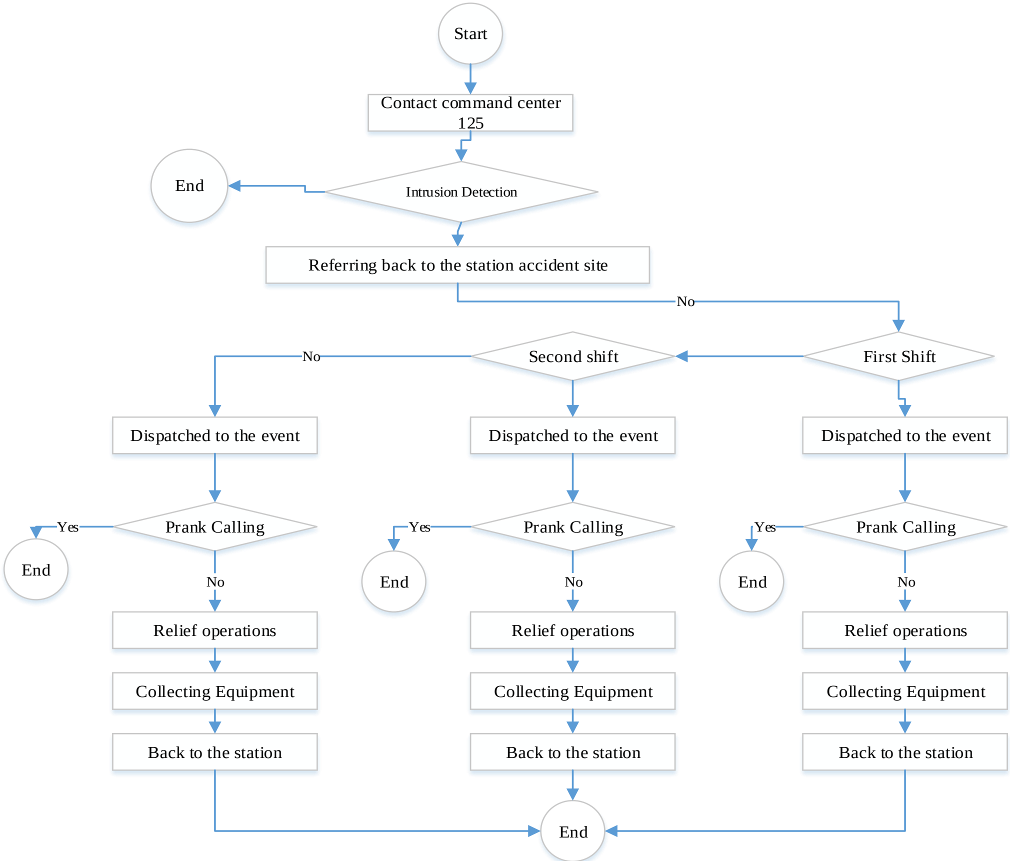

Figure 1. Process diagram fire

Regarding the recognition system, the following objectives can be defined for simulation:
- The percentage of resources employment in each station.
- The percentage of non-responsive system to incoming calls.
- The total number of nuisance calls.
- The number of nuisance calls which relief team dispatched to the place.
- The average time of operation for each station.
- The average time to arrive at the incident.

The entire operation includes arriving at the incident location, performing the related operation, leaving the location and returning.

4.2. Operational Definitions

Arriving at the incident location; the time between the call to 125 and the time when firefighters arrive at the incident. Operations: like rescue operations, fire suppression operations, etc. Leave time: The time between the ends of the operation and returning to the station. Return time: The time between leaving the incident until the deployment of forces and placing the equipment in the station.

5. Data Collecting

Statistical data were collected from center of statistics and information of Sari Fire Station and the data archive were collected 2015/06/22 until 2015/07/23. The study has faced limitations such as lack of confidentiality of information and non-mechanized fire-fighting system. The collected information includes all dialed calls to (125) center in a whole day and the referral calls to Sari fire station. The required data for this study includes:

- The time between arrivals of the calls
- The arriving time at the incident for each station.
- Operation time for each station
- Leaving time for each station
- returning time to the station

Using Minitab 17 software, the sampled data have been examined and its distribution function has been estimated. Figure 2 is the estimation of time between calls distribution function in the fire station. At this time of the sampling, 200 samples were randomly assigned to different days in a month in three shifts.

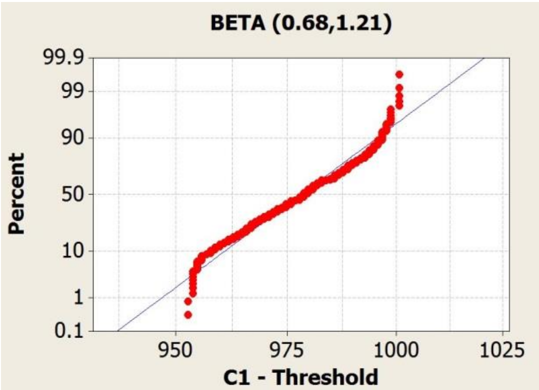

Figure 2. TBA (Time between arrival Expression: BETA (0.68,1.21) Chi Square Test Corresponding p-value = 0.607

Figure 3 and figure 4 respectively estimated arrival time distribution function of fire truck to the incident in the first and second shifts. At this time of sampling, two hundred samples were randomly assigned to different days in a month in three shifts. This period of time includes the interval between calls to the center (125) and when the firefighters arrive at the incident.

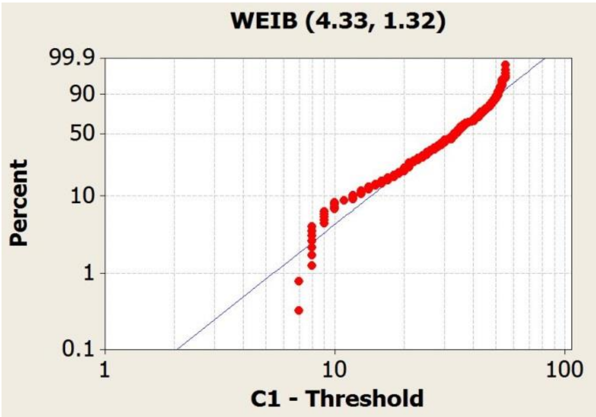

Figure 3.The first time to the event shift: Expression: WEIB (4.33, 1.32) Chi Square Test Corresponding p-value < 0.005

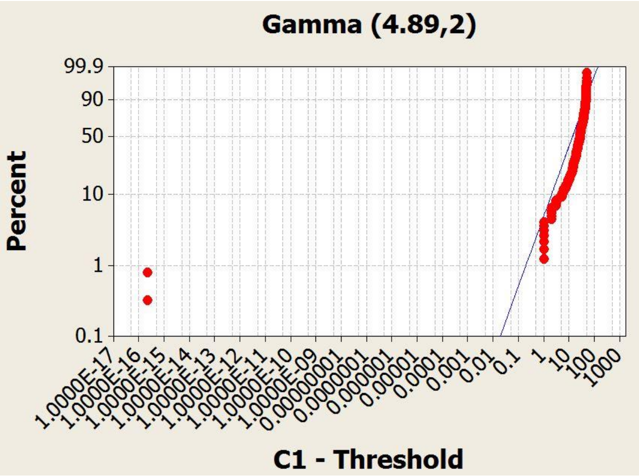

Figure 4. Time to reach the event in the second shift: Expression: Gamma (4.89,2) Chi Square Test Corresponding p-value = 0.616

Figure 5 and figure 6 respectively are the estimation of the distribution function of the whole operation in the first and second shift. At this time of the sampling, 200 samples were randomly assigned to different days in a month in three shifts. Observations show that return time distribution function for the first and the second shift is Weibull distribution.

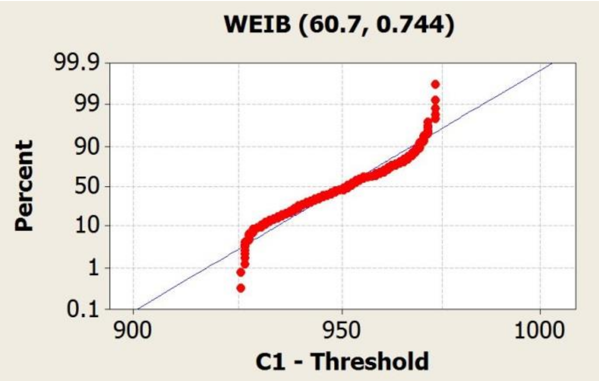

Figure 5. Total time shift operation in the first: Expression: WEIB (60.7, 0.744) Chi Square Test Corresponding p-value < 0.005

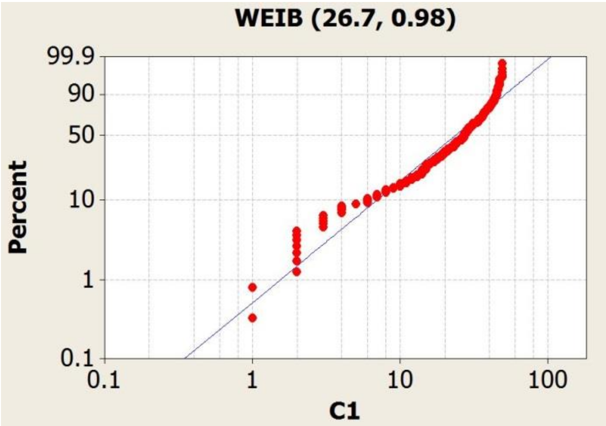

Figure 6.Total time in the second shift operation: Expression: WEIB (26.7, 0.98) Chi Square Test Corresponding p-value = 0.68

Figure 7 and figure 8 show the estimation of leave time distribution function by relief group in the first and second shifts. At this time of the sampling 200 samples were randomly assigned to different days in a month in three shifts. Observations show that return time distribution function for the first shift is the Weibull distribution and for the second shift is Lognormal.

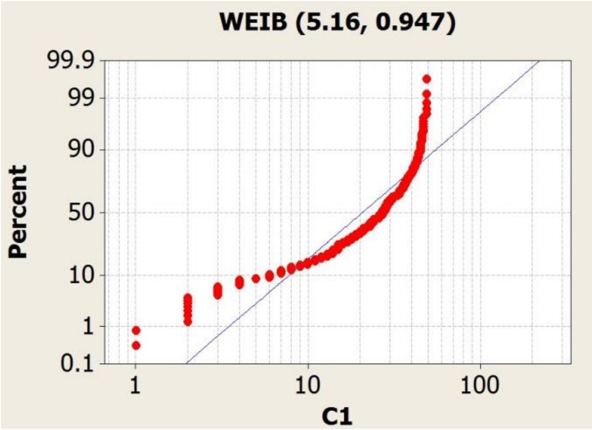

Figure 7. Since leaving the first shift: Expression: WEIB (5.16, 0.947) Chi Square Test Corresponding p-value < 0.005

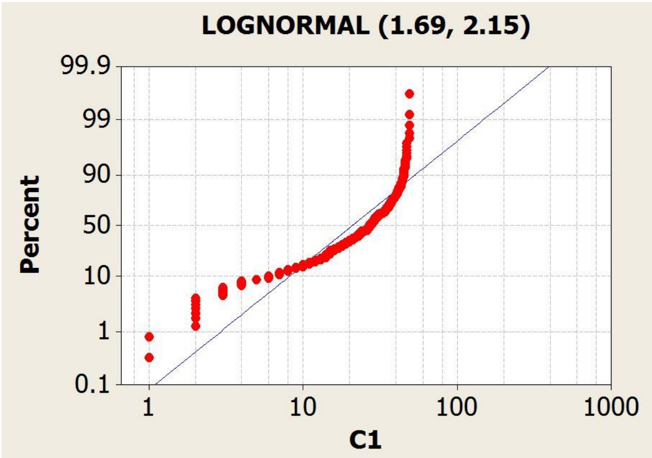

Figure 8. Since leaving the place in the second shift: Expression: LOGN (1.69, 2.15) Chi Square Test Corresponding p-value < 0.005

Figure 9 and figure 10 show the estimation of return time distribution function by relief group in the first and second shifts. At this time of the sampling, 200 samples were randomly assigned to different days in a month in three shifts. Observations show that return time distribution function for the first shift is Erlang distribution and for the second shift is Weibull distribution.

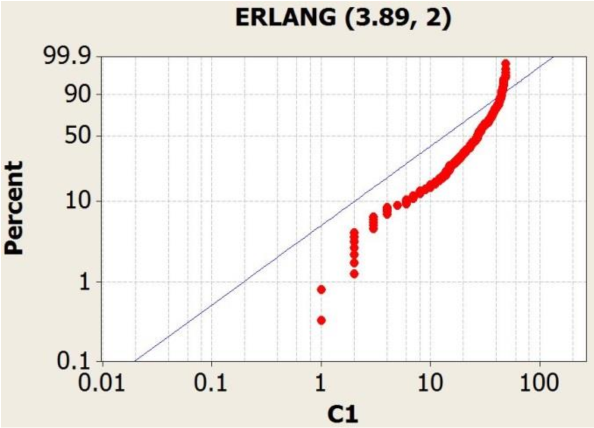

Figure 9. Since returning from the scene of the first shift: Expression: ERLANG (3.89, 2) Chi Square Test Corresponding p-value = 0.0259

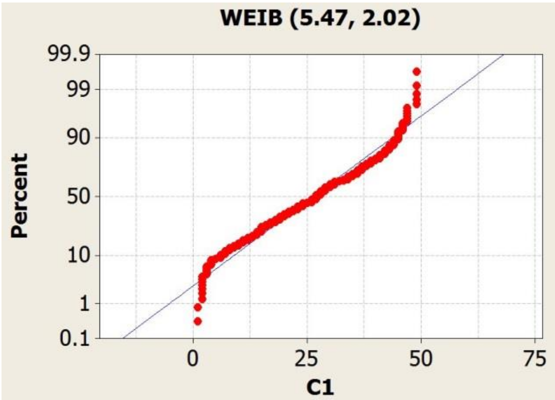

Figure 10. Since returning from the scene in the second shift: Expression: WEIB (5.47, 2.02) Chi Square Test Corresponding p-value < 0.005

5.1. The estimation of firefighting trucks downtime distribution function

Meantime between failures (MTTF), means the average time that a device, machine or device fail to operate for the first time. Moderate amount of downtime usually follows a particular distribution functions. The estimation of downtime distribution function of firefighting trucks can help decision makers in the better estimation of simulation and calculation of machineries working time through enterprise dynamic software. Table 1 shows the amount of downtime of fire trucks during a month and Figure 11 shows the estimation of the distribution function of fire firefighting equipment failure using Minitab17 software.

Table 1. Downtime of firefighting trucks

Sample	Life hours	Sample	Life hours
1	14341	16	75055
2	14457	17	82230
3	21006	18	106811
4	24225	19	123062
5	24225	20	128740
6	27869	21	134954
7	28365	22	149688
8	33346	23	162829
9	35879	24	175233
10	40684	25	208288
11	48206	26	233574
12	50046	27	316635
13	59422	28	466522
14	65641	29	667595
15	66701	30	715988

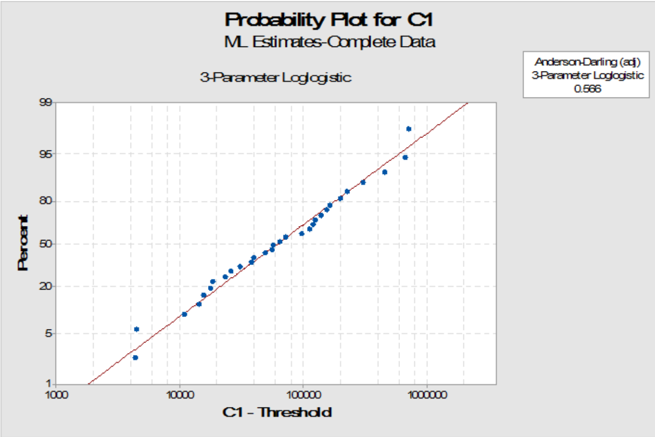

Figure 11. Distribution function of downtime in firefighting trucks

Considering Anderson-Darling amount that is equal to the lowest amount of 3 parameter Log Logistic distribution is 0.566. Parameters amounts of this distribution are respectively 11.004, 0.76 and 9965.06 for location, scale and threshold parameters.

6. Model explanation

Source 1 atom represents the sequence of received calls to the command center 125. Atom server 3 describes the process of answering to the received call. In atom queue 4, 5% of received calls are detected as nuisance call and are transmitted to Queue 6 atoms and labels are assigned to these calls. Half of these calls are recognized and the other halves which are not recognized will be transferred to the next stage that is queue 5. At this stage based on specified schedule (Time Schedule and availability atoms) the received orders are allocated to server 10, 11 and 12 atoms. At this time fire trucks move toward the mentioned location. At this stage some nuisance calls can be detected and these calls enter queue 10, 11 and 12 atoms. In server 11, 12 and 13 atoms, the relief operation begins and after the end of relief service equipment is collected in queue 16, 17 and 18 atoms and relief cars return to the stations. The amounts of obtained distribution functions of machineries will be entered in the MTTF part.

7. Model Performance

This model is done by Enterprise Dynamic software in the system core 2 due CPU and 4 GB of RAM 2.00 GHZ implemented. Warm-up period is considered equal to 1 hour. After simulation of model with Enterprise Dynamic software, output information for ten times run during one month (43,200 minutes) are presented in table 2.

Table 2. Simulations results with 10 runs

Description of Operation	**Results**
The average number of calls to 125 in a month	1196655
Average number of calls referred to all stations in a month	11933
The average number of transferred calls to other stations	14
Average number of calls without receiving services	3
The average time of arriving at the incident	5.23
Average of total time operation	5
Percentage of resources employment	3.70

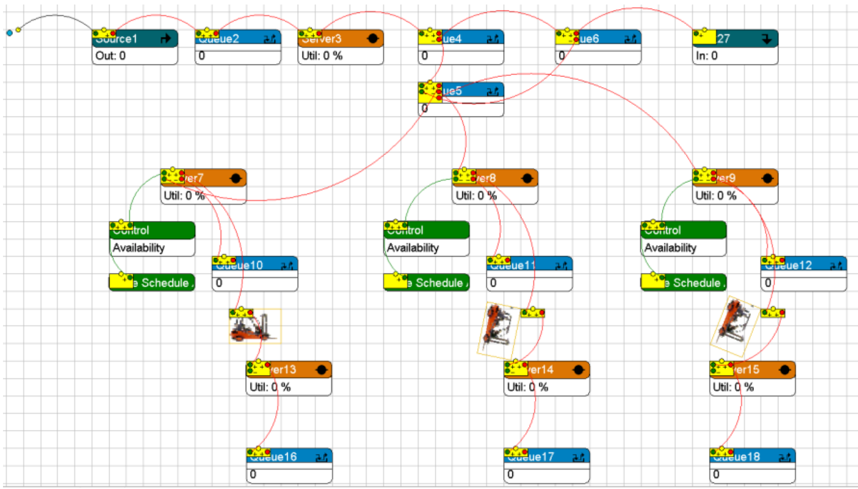

Figure12. Result of Enterprise Dynamic Simulation Software

7.1. Model validation using system historical information

According to the historical data of Mazandaran Public Relations Manager of firefighting center with Fars News in 2018, one million and 751 thousand and 391 calls were dialed to the commander center 125. The statistics was around 4 thousand and 800 cases during a day. On average, about 95 percent of calls during a day was related to the fire department and led to the operation and the remaining 5 percent were nuisance calls or the citizen's mistaken calls to firefighting center that were going to call the centers such as Water and Sewage organization, electricity or even purchasing safety devices. According to the available information the model can give us a good estimation of reality.

Table 3. Validating the model with reality

Description of Operation	Actual Information obtained	information from simulation
The average time of arriving at the incident	5.19	5.23
The average time of entire operation process	66.85	53.51
Percentage of stations resources Employment	3.95	3.7
The total number of calls to 125 in a month	145.949	119.655
The number of referral calls to the station	14.595	11.933

Figure 13 shows the map of the selected location for Sari fire station. Selecting the specified location for the fire station will maximize the radius of coverage and minimize the time of relief to the affected areas.

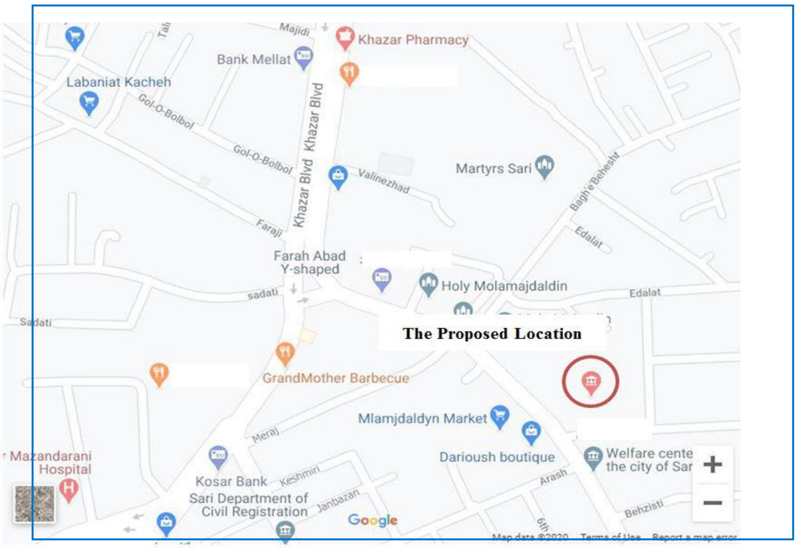

Figure 13. Geographical map of the proposed location

7.2 Designing and running the new model

Transferring call from one station to another one with appropriate equipment and human resources according to type of incident, takes at least two minutes. Based on achieved information we can say that the best time to control fire is in 3-5 minute. Adding to the number of fire-fighting stations is one of the best attempts in preventing fire incidents but because of the limitation in available places in a city and money to establish a fire station, adding to the number of new stations is impossible and is considered as one of the long-term plan for firefighting organizations. Another effective step to reduce relief time is increasing inside resources in stations, such as (Tankers, fire extinguisher, etc.). By adding to the resources, the number of transferred calls to other stations will be reduced or even zero in some places and the average time to get to the fired place will be reduced since time is not wasted. Each station can answer to all the received calls from commander center 125. The time when the firefighters get to the fired place will reduce too. Simulation information is presented in table5.

8. Validation of the proposed model results

For the validity of achieved information of simulation, according to the limitation in number of data Kolmogorov- Smirnov was used. Due to the limited data, this test is the best for one validation. For the Kolmogorov- Smirnov, SPSS software was used and the results are presented in table 4.

P-value accepted the zero hypothesis. There is no reason to reject the hypothesis that the "obtained sample from a normal distribution" does not exist. In other words, sample distribution is normal.

Table 4. Model validation by Kolmogorov-Smirnov statistic

Operation explanation	Kolmogorov-Smirnov statistic	Decision Criteria (P-VALUE)
The average time of arriving at the incident	0.435	0.991
The longest time for arriving at the incident	0.862	0.548
The average time for entire process of operation	0.598	0.866
Employment percentage of resources in stations	0.812	0.524

9. Model analysis, based on simulation results

As mentioned previously, the best time to control fire is 3 to 5 minutes. According to the simulation results transferring calls from one station to the closer station will be zero therefore average time to get to the fired place which was 2 minutes is reduced to 0.5 minute because of the transferred calls. Totally the average maximum time to get to the fired place is reduced too. By adding one resource to the station we see that there are no missed calls. It means that based on type of events all the dialed calls from commander center 125 are answered. Based on simulation results the percentage of employment resources did not change in comparison with its previous state and keep on its activity as before.

Table 5. The simulation results by adding to the number of firefighting resources

	Add one source	Add two source	Add three source
The average time of arriving at the incident	5.552	8.02	15
The maximum time for arriving at the incident	10	13	22.92
The average time for entire process of operation	34.265	46.23	49.11
Employment percentage of resources in stations	5.2	5	5
The number of transferred calls to another station	0	0	0

10. Conclusion

Trying not to waste time is the most important thing in an incident. Fast transferring of information to the firefighting center and presenting the report to this organization in relation to time, place and the reason of incident is a big help to do rescue-relief operations in a shortest period of time. One of the most essential attempts in emergency time is the management of human resources and equipment according to time, place and type of the incident. To optimize the inside resources in firefighting stations simulation software called Enterprise Dynamic was used. At the beginning of simulation the accuracy of calls in the commander center 125 will be investigated. Then the received calls will be referred to the most appropriate station based on its resources. In this research Minitab software was used to elicit calls distribution and the time of firefighting machineries downtime. Then through Enterprise Dynamic software we simulated the model and through SPSS software the model was validated. In this research the scenario of adding fire station resources in Sari was investigated case by case considering the downtime of firefighting machineries. In result 20% time reduction in arriving at the incident was achieved.

Since fire stations are usually lacking in resources, goods, and transportation vehicles for optimal responsiveness, proper planning to achieve the objective of efficiency and effectiveness of responsiveness considering the available resources and facilities is important. Although in small incidents where mentioned shortages are less frequently observed, fire station managers can do this planning to an acceptable extent; but if the dimensions of the incident become larger and beyond a small area, fire station managers alone cannot plan properly. It is in these situations that a proper tool for decision making and planning for managers seems necessary. So, this study aims to provide a model to meet the needs of managers in these situations. While the immediate responsiveness is usually the primary goal in response conditions, the simulation presented in this study also attempts to provide a program that minimizes the time of relief during the planning period, taking into account the actual logistics conditions.

In future researches we can conduct a study about separation of people's calls based on types of incidents, required equipment for that incident. In addition, the investigation of station resources in incident prone areas can be conducted as future studies.

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