Multi Criteria Decision Analysis (MCDA) of Unmanned Aerial Vehicles (UAVs) as a Part of Standard Response to Emergencies

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Abstract: Objecitve: To investigate whether the incorporation of Unmmaned Areial Vehicles (UAV) into emergency services is better than the manned drone and conventional means of transportation.Methodology: Multi Criteria Decision Analysis (MCDA) is applied to analyse four options to respond to emergencies. These four options are manned drone, UAV, helicopter and vehicle of incident commander. Findings: The UAV costs less than helicopters and manned drones and it is faster than incident commander's vehicle. The analysis based on three important parameters of response time, cost and availability of the option to reach at the scene of crash in most of the conditions, reveals that UAV is the best option. Application:Based on the findings of the study, it is recommended to include UAV as a part of standard response to emergencies.

Keywords: Automated External Defibrillator, fire and rescue services, multi criteria decision analysis, response time, and unmanned aerial vehicles

I. INTRODUCTION

Traffic accidents are very common around the world and every year thousands of fatalities are reported. There could be many reasons of traffic accidents, such as human mistakes or technical faults of vehicles or a mere combination of both that leads to an accident.

Traffic accidents result in financial as well as human losses such as deaths, physical injuries with psychological consequences for both survivors and their families. To minimize the loss due to traffic accident, Danish Road Safety Commission has developed a National Action Plan, 2013-2020 to reduce number of road accidents.

To meet the objectives of road safety as laid by EU, Danish authorities have set the goal of decreasing number of casualties suffered on road accidents of 2010 to halve by year 2020. To minimize the damage done by traffic accidents, Danish road safety commission has identified some areas of improvement. Their focus areas are speeding, alcohol and drugs, Inattention, failure to wear seat belts and helmets, Pedestrian, cycling and moped riders, young drivers up to age 24, accidents with oncoming traffic, single vehicle accidents and accidents at rural junctions. These factors are main causes of the accidents to happen. However, since 2012 the Danish Road Safety Commission has not reached any interim targets. In order to achieve its goal of reducing fatalities,

it is important to provide quick medical aid to inflicted persons. Because a quick and targeted response to traffic accidents can reduce the number of fatalities and severity of inflicted (Sánchez-Mangas et al., 2010). Every year due to delayed response, many inflicted persons die. For instance, in England alone during the past five years 35 people lost their lives (''The Guardian Uk'', 2016). Some studies found that in UK a targeted quick response to emergencies could have save three thousand lives (Paul Kendall, 2017).

Therefore, to achieve the target of lowering the fatalities because of traffic accidents, authorities should consider the induction of new technologies as a part of first responder rescue crew. For this purpose, incorporation of unmanned aerial vehicles (UAVs) is analyzed as part of first responders to emergencies by comparing it with conventional means of transportation with the application of Multi Criteria Decision Analysis. For the findings of this research, a hypothetical traffic accident at the roundabout of Korskro, in outskirt of Esbjerg, a town located on western coast of Denmark is considered.

A fire station located at Vibevej 18, Esbjerg is responsible to respond to a traffic emergency at Korskro roundabout. It is part of Sydvestjysk Brandvæsen (SVJB), which is a fire and rescue services with the jurisdiction of an area covered by the three municipalities including Esbjerg. SVJB administers 11 fire fire stations. The fire station in Esbjerg has an emergency setup where it dispatches a fire truck, a rescue truck and an incident commander vehicle to respond to the call if the number of persons involved in accident are up to five. According to Sydvestjysk Brandvæsen (2016) if there are many people involved in an accident then an appropriate response is dispatched.This research analyzed a case of traffic crash involving five people.

A. Application of Multi Criteria Decision Analysis (MCDA)

To find the worthiness of incorporating UAV into SVJB Multi Criteria Decision Analysis (MCDA) is applied. With the main parameter of agility of UAV to reach onsite, cost effectiveness and availability (viability of reaching at the scene of crash) are also taken into account for MCDA methodology.

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According to (Department for Communities and Local Government [DFCLG],2009) Multi-criteria analysis assists in decision-making process to find out the best option available in set of different alternatives. The decision making process becomes comprehensive with the analysis and ordering of all alternatives that includes, from the most acceptable to least acceptable alternatives.

For the induction of UAV into the system, monetary parameters are the cost related expenditures and non-monetary parameters are response time and availability. DFCLG (2009) categorizes this methodology into eight stages.

B. Establish the Decision Context

MCDA starts with the analysis of the problems, available options to solve problems and achieve the goals of a given situation.

According to traffic, related statistics 86 casualties were in year 2015 in Esbjerg. Overall, 7 people were killed 42 injured seriously and 37 injured slightly in road accidents (Statistics Denmark, 2017). To respond the emergencies three vehicles of fire station take on average 10 to 15 minutes to reach at the site of crash. The incident commander vehicle, which runs faster than other two vehicles, reaches in 10 minutes at Korskro while the heavy vehicles are expected to reach in about 15 minutes. It is assumed that there is a need to improve the response time.

C. Identification of the Options

To address the issue and come up with possible solutions, the identification of number of options are considered in the second stage of MCDA. There could be four options as a first responder to a traffic accident at Korskro roundabout as given in Table 1.

Number	Alternatives/ Options
1	Incident Commander Vehicle
2	Ehang-184 Manned Drone
3	Robinson R44 Raven I Helicopter
4	Ambulance Drone UAV

Table I: Different Options for MCDA

Three vehicles are dispatched as a standard emergency response. However, only incident commander vehicle for replacement with other means of transportation is considered. Rescue and fire trucks cannot be replaced by drones or helicopters, the latter two can either replace incident commander vehicle or assist in emergency response management. The advantages and disadvantages of selected alternatives are discussed one by one at length.

According to Sydvestjysk Brandvæsen (2016) the first and standard option to respond emergency is the incident commander vehicle with 80 percent probability that it shall reach at the site in 10 minutes. However, this vehicle is slower and expensive than drones. According to a university research article (Alec Momont, 2016) the response time should be 4 to 6 minutes in some severely injured person cases present at the site of accident. Therefore, considering either assisting or replacing incident commander from the rescue crew could be the option to reduce response time.

A manned drone Ehang-184 is considered as a second option. It can reach from fire station to the roundabout within 6 min due to fast speed. However, this drone has some limitations such as it cannot lift weight more than 100 KG. This will have a 23 minutes flight time roughly allowing 10 miles of flight distance, which is well within the distance between fire station and the roundabout. It is expensive with the price range of $200,000 to $300,000 (‘‘Dronethusiast, Home News’’, 2017). It can be ranked at initial stage of product life cycle with relatively higher level of technological readiness level.

According to the website of company of Robinson helicopter (https://robinsonheli.com/r44-raven-i/) the Robinson R44 Raven I is a small helicopter that can be considered as the third option. As comparing to Ehang 184, it has maturity stage of its product life cycle with better payload of 351 KG and faster speed of 200 km/h. However it is important to note that fixed and variable cost of the helicopter is very high comparing to other alternatives. For this option, the ambulance helicopter of Danish emergency medical services can also be considered. However, it has a price of around 22 million DKK with yearly cost of operations and averaging per flight expenses of 35,000 DKK (Kjellberg et al.,2012). However, a Lightweight helicopter like Robinson R44 is more comparable to manned drone for carrying first aid toolkit and at least one person to the incident site. Helicopter and manned drone would need open space without trees, fences, poles, buildings etc. to make landing and taking off practically viable.

The fourth option is to use unmanned aerial vehicles (UAVs). Based on different aspects of speed, price and availability, a UAV like ambulance drone is compared with rest of the options. With the capability of carrying payloads such as automated external defibrillator (AED) and having a speed of up to 100 km/h, this drone can play a vital role in emergencies. Once this drone reaches at the scene of accident, the emergency management dispatcher can assess the situation and communicate with the bystanders via video feed. (‘‘Mail online, Science’’, 2014). Successful application of AEDs by nonprofessionals is currently 20%, which can be increased to 90% with the live assistance by a professional via this drone (Alec Momont, 2016). However, this drone is also at the initial stage of product life cycle.

The second stage has identified four options that can potentially be considered for further analysis.

D. Identification of Objectives and Criteria Objective

Identification of the objective is the third stage of MCDA Methodology. For this purpose the fundamental objective hierarchy (FOH) is developed. According to Clemen and Reilly (2013) FOH is a tool that indicates the overall objective of decision by structuring the fundamental objectives into a hierarchy. It helps the decision makers to stay on right track of decision-making process as depicted in the following figure 1.

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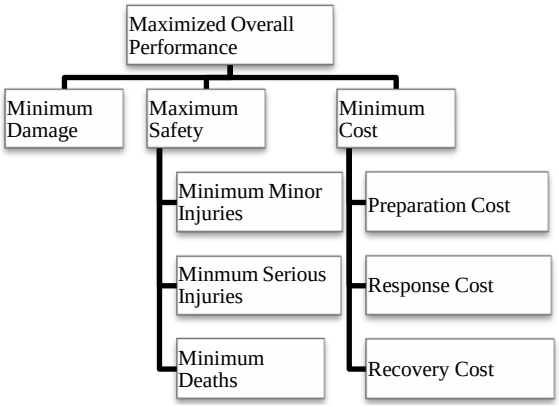

Figure. 1 Fundamental Objective Hierarchy

In case of Danish emergency management services, the main objective in the FOH is to maximize overall performance with maximum possible safety with minimum expenditures.

As for as cost is concerned it can be split into three parts, preparation cost, response cost and recovery cost. The preparation cost is the cost incurred by the authorities to carry out the operations and rescue injured person involved in accidents. Costs spent on rescue trucks, fire trucks etc and building such as fire stations and wages of relevant crew. Moreover, the response costs are the costs that are incurred by the authorities by responding to emergences. In case of Korskro traffic accident, the fire station at Vibevej 18, 6705 Esbjerg Ø dispatches inspector's vehicle, drone or helicopter. The expenses incurred on this response and rescue operation will be the response cost of this accident.

Recovery cost is the amount of resources spent by the relevant Danish authorities to cover medical expenses of injured person, insurance and any other financial losses and material damages to the property and vehicles involved on roads. According to the statistics of Transportministeriet (2010) Denmark, a serious injury due to traffic would mean a loss of 2,963,577 DKK to Danish economy.

Under this stage, it is assumed that with best available option and its application Esbjerg emergency management performs rescue operation for maximum safety of the persons involved in traffic accident with minimum resources dispatched. This application will lead to an overall improvement of performance of emergency management to meet its prime object of maximized safety with minimum cost as FOH fig 1 shows it.

2.Criteria: There is a need to consider some parameters as decision criteria. There are three main parameters in this case,

- Response time (assessment and first aid)
- Total cost (price and operational cost)
- Availability.

The selected parameters has certain reasons. These reasons helped to choose these parameters that lay down the foundation of selection of available options.

Response time has a chief importance, as mentioned before there are some death observed in UK due to delayed response time (''The Guardian Uk'', 2016). Moreover, in UK, out of 32 only 2 ambulances reach within eight minutes of emergency alert. Apart from traffic accidents, some experts estimated that 3,000 more heart attack victims could be saved each year if 90 per cent emergency calls were answered in that time (Paul Kendall, 2017).

In case of Esbjerg, the SVJB fire station's standard response time for emergency response services is 10 minutes. However, in case of serious injuries such as cardiac arrest and brain injury the time available for saving a life is 4 to 6 minutes (Alec Momont, 2016).

A bystander or the incident commander who can arrive at the scene of crash by one of the available options (i.e. vehicle, helicopter or manned drone). According to a research if an ambulance drone carrying automated external defibrillator (AED) is sent to the site and bystander uses it for the treatment of victim then the survival chances increases to 38% before the arrival of a professionals (Iwanicki, 2010). The importance of considering response time as a main parameter is evident from these facts.

The second important parameter of the decision criteria is cost of the different options. Option such as helicopter has the quicker response time than vehicle and carrying more loads makes it favorable than drones but it comes with a huge cost to buy and operate comparing other options. Therefore, in order to keep a check on price, the helicopter option in emergency services might not be optimal. Under this analysis of MCDA, the cost parameter is included to achieve the second part of the main objective.

Another parameter is availability, which means that at the time of accident, the option under consideration can reach at the site of accident and take part in rescue operation. For example due to rush hours and traffic jams, incident commander's vehicle will take longer time to reach at the accident site. Another option like helicopter or drones may not be a good option to be part of emergency response during a bad weather like a storm. Table II shows all parameters with relevant attributes.

Parameters	Attributes
Response time	Minutes
Total Cost	DKK
Availability	Undefined

Table II: Parameters for Decision Making

In table III different parameters with its relevant attributes are given. The response time has its natural attribute called minutes, likewise cost is shown in DKK and attributes for availability is undefined.

E. Scoring of Options

Scores are assigned to different options because scoring can combine attributes of different parameters. Some parameters for decision making have a monetary and some have non-monetary value and nature, therefore scoring is applied to combine both parameters.

Under this process of scoring, the least preferred option will receive minimum scoring whereas most preferred option will get maximum scoring. The most preferred option is determined on relative scoring. Relative scoring is used to replace the consequences with the numbers and all parameters are scored accordingly.

F. Response Time

Options	Response Time Minutes	Scoring
Incident commander vehicle	10	24
Manned Drone	05:16	46
Helicopter	02:38	100
UAV	05:16	46

Table III:Response Time and Scoring

In table III, the response time of helicopter is fastest with 200 km per hour (https://robinsonheli.com/r44-raven-i/) resultantly, it received 100 scoring points. It can cover the distance of approximately 8 km (from fire station to accident site at Korskro roundabout) within 2 min and 38 seconds. Whereas the speed of manned drone and UAV is 100 km (‘‘Dronethusiast, Home News’’, 2017) meaning that these two options will reach at the accident site in 5 min and 16 seconds. However, according to SVJB response time for incident commander's vehicle is 10 min.

G. Cost

Soring based on cost is shown in table IV.

Alternatives	Price in DKK	Scoring
Incident commander’s vehicle	450,000	29
Manned Drone	1,696,353	8
Helicopter	2,612,383	5
UAV	128,923	100

Table IV:Price scoring

Sydvestjysk Brandvæsen (2016) esitmates the cost of incident commander’s vehicle around 450,000 DKK. Manned drone, helicopter and UAV prices were in dollar and converted into DKK. The conversion rate is 6.89 on 15-05-2017. The price of the manned drone is $200,000 to $300,000 an averaged of the price is taken and converted into DKK(‘‘Dronethusiast, Home News’’, 2017). Helicopter price is $ 385,000 similarly, the price of UAV $ 19,000 (Mark Prigg, 2014). UAV received highest number; as the price of the UAV is lowest among all options.

Availability**:** It is vital for emergency response that the options under consideration can reach at the scene of crash in most of the circumstances and different weather conditions. Under availability, it is considerable that whether it is possible for helicopter to land and take off at scene of emergency and whether the person flying in manned drone or helicopter is being exposed to some danger or not such as heating due to fire, chemicals or radioactive etc. These factors can endanger the rescue operation. According to the statistics of weatherspark website (https://weatherspark.com/y/61730/Average-Weather-in-Esbjerg-Denmark) there is however only 4 % probability that the weather conditions would be extreme. However, according to statistics there is only 4 % probability that the weather conditions would be extreme. The scoring for availability is shown in table V.

Availability (Assumed)	Scoring
Incident commander vehicle	80
Manned Drone	60
Helicopter	30
UAV	80

Table V: Availability Scoring

The incident commander vehicle received 80 scoring point. According to Sydvestjysk Brandvæsen (2016) there is 80 percent probability that inspector will reach in 10 minutes. The helicopter received 30 scoring points, the reason for this is that it is very difficult to decide by the emergency responder whether the helicopter can land and take off at a particular site or not. Basically helicopter needs some specific surfaces and open area to land and fly. However, it has a benefit of withstanding stronger winds and rains than drones; the incident commander's vehicle does not have these issues. Moreover, the helicopter and manned drone can put humans flying in them to dangers of heating and chemicals depending on the type of emergency. However, the fourth option of UAVs does not have this issue. UAV has big advantage than other options that it does not expose its controller to dangers. Therefore, the scoring number for the availability of UAV is assumed 80 and for manned drone 60. The manned drone received lower scoring because of limited flight capability, low technological readiness level and its initial stage of product life cycle. To remain unbiased about the availability scoring and other assumed scoring, sensitivity analysis will be performed to see the impact on results with different scoring.

H. Weighting to Options

The preference scales still cannot be combined because a unit of preference of different options are different. Therefore, the concept of the weight is introduced in decision-making process. As per the DFCLG (2009) report, the weighting depends on the subjective knowledge of the experts; therefore, it always needs to be handled with care, because personal biasedness can influence weight assigned to some parameters. To remain unbiased, for the application of MCDA analysis to a traffic accident at Korskro roundabout equal weights are assigned to all parameters for simplification (DFCLG, 2009).

I. Combination of Weights and Scores

The total preference scoring for each option is the weighted average of its scores on all the criteria. Table VI depicts the overall calculation and results.

Options	Response time	Price	Availability	Total scoring
IC Vehicle	24	29	80	44
E-Hang Manned Drone	46	8	60	38
Robinson R44 Raven I Helicopter	100	5	30	45
UAV	46	100	80	75
Weight	33%	33%	33%	1

Table VI : Overall Scoring

In table VI all parameters are given the equal weight, as result the ambulance drone UAV outperforms the other alternatives.

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A. Examination of the Result

The examination of results of the previous stage is carried out under this stage of the MCDA. Total scoring of UAV is higher than the other options. The option of helicopter cost is too high that cannot be reduced, whereas the price of manned drone does not seem to be final. It is expected to decrease; however, it is not available for operations and sales in the market due to initial stage of product life cycle. Nevertheless, if the price of manned drone decreases once it gets established itself in the market, the decrease in high costs may effect on the total performance of it. Moreover, a change in the weights of the parameters will change overall performance.

B. Sensitivity Analysis

Sensitivity analysis is applied to know the importance of the parameters in the context of decision-making process. Some experts may not be agreed on choice of weights and assumed number of scoring to options. This disagreement of experts can be solved by using sensitivity analysis (DFCLG, 2009).Response time is considered the main parameter, because first aid and real assessment depends on the response time; therefore, its weight has been increased to see the overall impact on the result. Likewise, the parameter of availability has a direct impact on the survival of the inflicted person; therefore, its weight has also been increased whereas price does not have a direct impact on survival of the inflected person therefore its weight has been decreased in this sensitivity analysis. After doing so UAV still outperforms the other options. Sensitivity analysis is shown in the table VII.

Alternatives	Response time	Price	Availability	Total scoring
IC vehicle	24	29	80	47
E-hang Manned Drone	46	8	60	44
Robinson R44 Raven I Helicopter	100	5	30	53
UAV	46	100	80	70
Weight	40%	20%	40%	1

Table VII:Sensitivity Analysis

The price of helicopter and incident commander's vehicle are fixed, whereas due to fast developments of manned drone and UAV technology price does not look final, it is expected to decrease. If in the future, the drone's price decreases, it will have further positive impact on the preferred option.

C. Discussion

UAV is the option with highest scoring however, for the purpose incorporating it into emergency services two parameters are required:

- The implied cost of averting a fatality of a severely injured person
- Socio-economic benefit of saving a human life.

As for as the first parameter is concerned, the implied cost of averting a fatality is the price of ambulance drone and its operational cost. The price of ambulance drone is 128,923 DKK taken from table IV and operational cost is assumed 1200 DKK for one operation. The total cost of averting a fatality will be equal to the price and its operational cost. For socioeconomic cost, "transport economic unit prices" are used. According to a Danish report (Danish road safety commission, 2012) Denmark, the transport economic unit prices are regularly calculated and updated by DTU transport and includes key indicators and unit prices to be used for valuation in socioeconomic analysis of the transport sector. In transport economic unit prices, both direct costs like hospital expenditures and indirect costs like welfare losses are included. The welfare loss is a cost that represents a valuation of loss of lives. Based on the transport-economic unit prices, the average socioeconomic costs per casualty on the roads are given in the table VIII.

Options	Price (A)	Per year OC (B)	Total Cost (A+B)	Socio Economic Benefit	Socio Eco. Benefit-TC
Manned Drone	1,696,353	138,945	1,835,297	14,334,375	12,499,077
Helicopter	2,612,383	213,975	2,826,358	14,334,375	11,508,017
UAV+ IC's vehicle	578,923	129,600	708,523	14,334,375	13,625,852

Table VIII: Average socio economic cost per causality (Transportministeriet, 2010)

In table VIII person, related cost and value of statistical life are shown for casualties. The total cost to the society of one fatality is 17,297,952 DKK and total cost of one seriously injured person is 2,963,577 DKK. To calculate the socio economic benefit it is simply taken the difference between total cost of per severely injured person and a total cost of a fatality that is shown in the equation 1.

$$17{,}297{,}952 - 2{,}963{,}577 = 14{,}334{,}375 \qquad (1)$$

If the incorporation of UAV into emergency services can save life of a seriously injured person due to quick response than the existing standard emergency response, the total socioeconomic benefit will be equal to 14,334,375 DKK. However, UAV should be used to assist the process of emergency management rather than replacing incident commander vehicle from standard emergency response because of different reasons. For example, UAV in some cases may perform some tasks but not all tasks of incident commander as well as UAV may not be able to fly in extreme bad weather conditions. Therefore, ambulance drone and incident commander vehicle should respond simultaneously in case of an emergency. However, this setup will increase the implied cost of preventing a fatality.

In order to find out the cost, total cost of averting a fatality of selected alternative over a one year is computed to see the impact of including an ambulance drone into emergency management for short term to medium term. For calculating total cost for one-year different costs added such as price of the option, operational cost and depreciation cost.

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However, due to lack of information of expected life of the drone, depreciation cost could not be included. However, the result seems to remain same by not including depreciation cost. The emergency operation lasts about 2 to 4 hours as per records of Sydvestjysk Brandvæsen (2016); here it is assumed that, emergency management will take on average 3 hours. According to Sydvestjysk Brandvæsen (2016) the operational cost is multiplied with 3. Per hour cost for the incident commander's vehicle will be around 500 DKK. Based on the operational cost of the incident commander's vehicle, 1200 DKK operational cost is also assumed for the UAV.

Operational cost for Robinson R44 Raven I helicopter will be 4,458 DKK. Similarly, based on the operational cost of the helicopter, 2,895 DKK operational cost for manned drone is assumed. Operational cost is considered for year 2017, in 2017 estimated number of accident in Esbjerg municipality will be 48 (Mehmood, S., & Ahmed, S, 2017), therefore, operational cost of all options is multiplied with the 48 estimated number of accidents. The detail comparison of the socio economic cost vs benefit is shown in table IX.

DKK per Injury	Per Fatality	Per Severely Injured	Per Lightly Injured
Person related cost	1,595,395	922,245	289,379
Welfare loss ("VSL")	15,702,556	2,041,332	157,026
Total Expenditures	17,297,952	2,963,577	446,405

Table IX: Per Year Cost VS Savings Comparison of Selected options

In the table IX a new option UAV + incident commander vehicle is introduced, as it is concluded that unmanned aerial vehicle cannot exclusively replace but it can assist incident commander. The cost of the incident commander's vehicle and UAV are added together to determine their net effect as shown in the above table. The prices of the manned drone and helicopter are taken from table IV. The cost on operation is multiplied with the total number of incident to calculate the per year cost. Total cost is the combination of price and operational cost. Socio economic benefit is the difference between cost of a one severely injured person and a fatality. By inducting a drone technology into emergency management, if one severely injured person life is saved by quick response, the total benefit to the society will be excessively higher than the cost of inducting this technology into emergency management.

II. LIMITATIONS

This paper examined and analyzed three important parameters of saving lives in traffic accidents, which are response time, cost and availability. However, there could also be some other parameters such as assessment of the site of accident, provision of first aid capability and operational costs. However, the inclusion of these parameters will not influence the final decision significantly because of being the low influence factors. Therefore, these parameters are not considered. The application of MCDA should be the assistance in decision-making. The final decision should not be completely based on the result of MCDA. The decision makers should take the final decision (Kujawski, 2003). This paper examined the application of UAV that canoperate Beyond Visual Line of Sight (BVLOS). The UAV flights for BVLOS operation are not yet approved in Denmark.

Moreover, there is a need to study further the acceptability of UAV in Danish public and integration of the UAV into emergency services (Mehmood et. al., 2017).

Any technological improvements needed and safety measures to be considered for the role of UAV as a part of first responder's community is not considered in this paper.

III. CONCLUSION

The multi criteria decision analysis based on parameters of response time, price and availability of the option reveals the usefulness of UAV incorporation as a part of first responders. The incorporation of UAV along with the standard emergency response will add up the cost of emergency services but the socio-economic benefits will outweigh the costs by a huge margin.

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