Continuous Approach for the Transportation of Relief Items in Post-disaster Period of Large Scale Earthquakes

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Submitted to the
Institute of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Science
of
Industrial Engineering

Eastern Mediterranean University
January 2020
Gazimağusa, North Cyprus

Approval of the Institute of Graduate Studies and Research

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ABSTRACT

In the past decade, the use of an unmanned aerial vehicle (UAV) or drone which was mostly used in the military has been increased. They came up with this idea as an alternative to use the (UAV) transportation system instead of the usual package delivery (road transportation with trucks) also, as an additional tool (consider the truck as a station for UAV) for packages allocations in order to speed up the whole procedure. In this dissertation we extended and implemented the hybrid routing model by determining launching point and retrieve point subsequently for all these modification effect on operation time, consequently, in our own case, which is humanitarian logistics, it can rescue and save more people's lives.

Keywords: traveling salesman problem, transportation problem, truck- UAV, post disaster response, large scale earthquake and humanitarian logistic

ÖZ

Son on yılda, insansız hava araçları (İHA) veya çoğunlukla askeriyede kullanılan drone kullanımları artırıldı. Tüm prosedürü hızlandırmak adına, (İHA) ulaşım sistemini, alışılagelmiş paket teslimatına (kamyonlarla karayolu taşımacılığı) bir alternatif, ayrıca paket tahsisi için ek bir araç olarak (kamyonu İHA için bir istasyon olarak düşünürsek) kullanma fikriyle geldiler. Bu tezde, başlangıç noktasını ve geri alma noktasını belirleyerek hibrit yönlendirme modelini genişlettik ve uyguladık, ardından, bu işlemleri operasyon süresi üzerindeki tüm bu modifikasyon etkileri için yaptık. Sonuç olarak, insancıl lojistik olan bizim örneğimizde, daha fazla insanın hayatı kurtarılabilir.

Anahtar kelimeler: gezgin satıcı problemi, nakliye sorunu, kamyon- İHA, afet sonrası müdahale, büyük ölçekli deprem ve insancıl lojistik

DEDICATION

To My Parents and my lovely brother.

ACKNOWLEDGMENT

First of all, I would like to express my sincere gratitude to my dear supervisor, Prof. Dr. BELA VIZVARI for the continued support of my analysis and related studies, for his patience inspiration and immense knowledge His encouragement has motivated me to prepare and compose this article all the time. I'm very thankful from Prof. Dr. János Tóth which helped a lot in formulation part.

I would like to thank dear academic personals in industrial engineering department and especially Dr. Sahand Daneshvar for his support and guidance during preparation of this study.

Also, I'm great thankful to Iliad Nabi Pour my friend which helped me a lot and my collegiates Mohamad Fallaha, and Aliyo because of their support during the thesis and I am grateful to them.

I owe quit a lot to my parents, specially my father, who allowed me to travel all the way from Iran to Cyprus and supported me all throughout my studies and my mother for her emotionally support during these years that without her I couldn't stand.

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LIST OF ABBREVIATIONS

SAR	Search and Rescue
TSP	Traveling Salesman Problem
TSP-D	Traveling Salesman Problem with a Dron
UAV	Unmanned Aerial Vehicle

Chapter 1

INTRODUCTION

Is a UAV the same as a Drone? Drones and UAV's are quite similar in the sense that they do not require any piloting and both remotely controlled or via the use of a software. Drones can also be called UAV's but generally, UAV's are mostly used in the military aircraft while drones as hobby quadcopters. Some people often interchange UAV's and drones, they are practically considered to be the same in several research because of their same function. In this study, we considered a UAV for the delivery model, but all calculations can also be applied on drones.

1.1 History on UAVs and Drones

Unmanned aerial vehicles (UAVs), commonly called drones, come in a different forms and sizes to fit a myriad of applications. They were firstly used by the military unit in the 1990s. They gained public notoriety for their use in military contexts, particularly by the United States in middle east and some African countries (Smith., n.d.), (Nemhauser, 2011).

In non-military terms, the planned and real use of drone has been increased. A study carried out by the association of UAV international estimated that the total economic impact of drones and related systems throughout the US would be $82.1 billion among 2015 and 2025 (Smith., n.d.). The Business Insider's Intelligence Unit is trying to project drone sales to reach $12 billion in the year 2021 (Meola, 2017).

A number of firms capitalized on drones via cinematographic capabilities. Such companies are selling their drones to both professional filmmakers and hobbyists. For the first time Amazon unveiled “prime Air drone” delivery system in 2013 (Banker, 2013) and conducted its first Prime Air operation in England in December 2016 (Perlow, 2016), DHL also carried out an effective examination for distribution of medical equipment through parcelcopter drones. (Bryan, 2014), FedEx and so on are using this technology to deliver postal parcel to their customers.

Figure 1.1: Truck and quadcopter

Moreover, the rapid growth in technological devices has led to a cost reduction of drones, which makes more suitable candidates for a wide set of services such as health services. however, health services and medical resources nowadays have had some restrictions in underserved communities mostly because of difficulty in vehicle transport and in-person interactions as such, the usage of drones can be efficient in such areas to deliver the health and service program. Current research has looked at the use of drones for natural disaster relief, search and rescue operations, and transition vehicles. (Sharon Wulfovich, 2018)

Rwanda's transportation infrastructure is restricted beyond major cities. Zipline delivers blood bags from a single refrigerated blood bank to distant hospitals and transfusion centers. Delivery that once took two hours by car can only take 20 minutes. (L. Kuo, 2017) Hospitals in Switzerland have used Matternet's services to carry medical supplies quickly between hospitals. Company drones are capable of carrying four pounds of products up to 12 miles (Leary, 2017).

Drones usage have aided in recording havoc and disaster in the post- disaster scenarios such as the April 2015 earthquake where over 7,500 lives were lost in Nepal. Drones were used to survey the damages in areas such as the remote mountain villages, this helps a lot in prioritizing relief efforts (Newsome, n.d.). The usage of drones was also seen in North Carolina (Engelking, 2015) and Texas (Ferris-Rotman, 2015)for identifying the direct emergency response to people affected by flash blood. Collection survey of the images in catastrophic scenarios was given by Adams and Friedland (Friedland, 2011) via the usage of drones.

many different approaches such as longer endurance, development in communications systems, increasing carrying capacity and deduction of producing cost are used to makes deliveries speedier especially in healthcare and post-disaster response which reducing operation time even a couple of minutes may save more people's lives.

1.2 Study Outline

The rest of this dissertation is organized as follow: Chapter 2 is dedicated to review of the literature reporting similar researches. Variety of viewpoints is explained and the outcomes of carried out surveys are summarized. Chapter 3 explains the methodology used in this study. Chapter 4 case study on Nepal. Computational analysis is done by python. Finally, Chapter 5 concludes and future study by providing ideas in order to cover all issue related to UAVs and speed up procedure. Appendices include the results obtained during the run of Python application also the whole codes which used in this study.

Chapter 2

LITERATURE REVIEW

Proper and prompt supply allocation for the post-disaster events are extremely crucial for the increase of rate of survival (Ji & Zhu, 2012; Q. Wang & Rong, 2007). Caunhye, Nie, and Pokharel (2012) addressed the importance of the urgent distribution of resources such as medicine, food, water, and diapers in their study to reduce the fatality caused by starvation or diseases. Therefore, many researchers have focused on how to allocate these supplies as quick as possible to the areas affected by disasters.

Khayal, Pradhananga, Pokharer, and Mutlu (2015) proposed a network flow method for location selection of momentary facilities for the supply distribution. Similarly, Camacho-Vallejo, Gonzalez-Rodriguez, Almaguer, and Gonzalez-Ramirez (2015) applied a bi-level mathematical programming to minimize the distribution time of international aid. After initializing a bi-level model, the mentioned study reduced the problem to a nonlinear single level, and then a linear model in order to obtain a mixed-integer programming model. They applied their findings on an earthquake case located in Chile in 2010.

Due to nature-complexity of resource allocations, many researchers used heuristic and meta-heuristic approaches for problem solving of such scenarios in order to find near optimum solutions. For instance, Lei, Lee, and Dong (2016) developed a heuristic model for resource allocation for after disaster missions. In their study, they focused on operation scheduling problem related to supply distribution to areas of disaster. In their model, they considered lead times of processes namely shipping, assembly and waiting times in order minimize the total tardiness of customer order fulfillment. Likewise, Mohammadi, Jula, and Tavakkoh-Moghaddam (2019) developed a hybrid meta-heuristic model to minimize the cost as well as maximum time of transportation for single-allocation of hub and its effect on uncertainties in supply delivery.

Considering all above-mentioned strategies for supply allocation, the matter of transportation itself is limited to availability of connective routes after a disaster. Blockage of roads after a disaster taking place in an area, could drastically increases the amount of time of supply delivery to the affected locations. Therefore, recent studies are focused on using Unmanned Aerial Vehicles (UAVs) for fulfilling such purposes (Nejdati, Vizvari & Izbirak), (Shavarani, Golabi, & Izbirak). These devices are capable of selecting straight routs to fly which can reduce both the distance and the time of transportation significantly and are not limited to the availability of ground routs towards the target locations.

2.1 Supply Allocation Using UAVs

The initialization of usage of UAVs goes back to the beginning of the 20th century where they were mostly used for aircraft test dummies and target training (Keane & Carr, 2013). Due to high cost of production of such devices, they were mostly produced as armed and for military purposes (Freedman, 2016).

However, with advancement of technology, UAVs are also used for commercial and humanitarian purposes. For instance, Yeong, King, and Dol (2015) investigated the utilization of drones on marine Search and Rescue (SAR) missions in both offshore and nearshore. The objective of using UAVs in this study was for aerial imagery, topographic mapping and urgent supply delivery. In their study they have mentioned the limitation of battery life of UAVs for such missions specially for offshore missions.

Due to the history of application of UAVs, one of the main challenges of implementing such devices for the humanitarian purposes is the negative public opinion towards UAVs. In this regard, Tanner (2018) conducted a questionnaire base study to address the privacy issues regarding the application of UAV for post-disaster and SAR missions in North Carolina, Virginia and Maryland in which UAV maneuvers utilized in recent years for SAR missions. Moreover, Hatfield (2017) considered both interviews and questionnaire base methodology to demonstrate a general guideline for the application of UAVs in such missions. Data were collected form experts and ground teams, firefighters and police force regarding the utilization of UAVs for SAR missions. One of the significant findings of this study was the strong correlation between negative attitude towards UAVs and education gaps. Then Hatfield (2017) addressed this issue suggesting the implementation of educational programs regarding benefits of UAVs. These issues regarding negative public perspective are tackled by some legislations and policies in some countries. For instance, Chand (2018) investigated the effect of legislation, policies and regulations of utilizing UAVs for the purpose of public safety and emergency management. The legal challenges and policies solutions given by the Canadian government related to the adaptation to UAV technologies, are also discussed in the aforementioned study. Accordingly, Table 1 shows some of the implementation of UAVs for humanitarian applications (Chen, Zhang, & Xu, 2014; de Oliveira Silva, de Mello Bandeira, & Campos, 2019).

Table 2.1: Application of UAVs in humanitarian area

Country	**Purposes**
Australia	SAR operations
Canada	For cellphone signal for communication with victims
Congo	To analyze local population immigration for protection purposes
Dominican Republic	Supply delivery for out of access areas
Rwanda	Transportation of medicines
England	SAR operations
Haiti	Assessment of infrastructures and water mapping
Japan	For aerial imagery of damaged reactors after the tsunami
New Zealand	SAR operations

One of the important application of UAVs in post-disaster missions, is the aerial imagery of the affected area. Data such as 3D mapping of infrastructure of the buildings, roads and connective routes of the area can be quickly gathered using drones. For example, Greenwood (2018) investigated the aerial imagery for post-earthquake analysis of damages in infrastructures, buildings and roads with the help of UAVs. Using structure form motion technique, he used UAV to take 2D and 3D images form the surface of the affected area. In addition, as analyzing huge amount of aerial images on post-disaster missions is time consuming, overwhelming and involves human error, Axel (2017) developed a novel full automated image processing algorithm to detect and investigate the infrastructures of roadways and damaged buildings using airborne images.

It should be mentioned that, data processing and controlling multiple UAVs by operators always accompany huge amount of workload on operators and are exposed to human errors. Hence, Durga (2011) assess the amount of cognitive workload on

UAV operators in cases where the operators need to control one or two UAVs simultaneously. Their findings showed a significant increase in failure of vehicle control when the participants were tasked to control more than one UAV.

Even though in recent years, UAV base operations are more cost effective, in case of utilizing several UAVs, cost of operations should be taken into consideration. In this regard, Chowdhury (2018) developed a mixed integer-linear programming model for UAV routing in order to minimize the cost of utilization for post-disaster missions. Factors such as number of UAVs, battery recharging cost, UAV maneuvering costs, etc. were taken into consideration for the development of the mentioned model. In this study, the problem solved by both adaptive large neighborhood search and modified backtracking adaptive threshold accepting heuristic algorithms. The demonstrated results shows promising solutions and the study was validated in a real-life case study (Chowdhury, 2018).

From the strategic perspective and operation planning of UAV base humanitarian missions, the implementation of a correct decision making is vital to have optimum performance of such devices. Therefore, de Oliveira Silva et al. (2019) proposed a decision-making process for structuring UAV aid delivery strategies in post disaster missions. They based their method on a real-life disaster event which took place in Brazil in 2013. Their findings focused on funding response team, facility location and distribution network approaches. Similarly, Chauhan, Unnikrishnan, and Figliozzi (2019) developed an integer programming model to maximize the coverage area for supplying necessary demand from a capacitated facility. UAVs were utilized in their model with limited amount of battery life and they solve the model using a 3-stage heuristic method. The mentioned method is capable of quickly finding near optimum solutions to this transportation problem which comes handy when the variables such as wind direction, sudden change of demand or demand location are rapidly changing. The method basically considers the number of trips UAVs are capable to do in a single charge of battery. Moreover, de Oliveira Silva, de Mello Bandeira, and Campos (2017) designed a procedure for distribution of aid supplies in post disaster missions using UAVs. In their study, UAVs are first operated to gather accurate geographical information from the affected areas and then distribute aid supplies in the mentioned regions. They also considered the location of service facilities within the affected region, and location of supply centers outside as well as vehicle routing and real time information distribution in the design of the procedure.

Some of these applications are not limited to UAVs, and, can be implemented in helicopter base missions as well. For instance, Xavier, de Mello Bandeira, de Oliveira Silva, Bandeira, and Campos (2019) developed a mathematical model to use helicopters as an appropriate tool to get access to victims in the areas affected by disasters. Their objective was to minimize the operation time considering multiple resources, vehicles and products for the mission.

As mentioned in studies above, one of the restrictions of utilizing UAVs in the humanitarian field is the battery life of the device itself. Therefore, recently some studies are leaning towards some more robust methods such as using mobile distribution center to utilize the drones for the last few miles traveling distance towards affected areas.

2.2 Truck and UAV Implementation for Resource Allocation

One of the approaches to utilize the mobile distribution center for UAV delivery system is to use traditional truck delivery system with the combination of UAVs. This method not only shows promising improvement of the delivery system, but also is capable of being implemented for delivery systems other than humanitarian purposes. In this regard, Ham (2018) developed a constraint-based model in order to schedule m-drone, m-truck and m-depot systems based on minimization of time. In this study which was mostly based on commercial purposes, after finishing the task of delivery, UAVs could either return to the truck for the next package or continue flying to a new location for picking up item from another customer and return to the truck. Moreover, Yurek and Ozmutlu (2018) developed a mixed integer programming problem for a single truck which carries a UAV to deliver products in targeted locations. In their model they were using an iterative approach, starting with considering the shortest path of delivery for the truck with the objective to minimize the total time of delivery for the problem.

Rabta, Wankmüller, and Reiner (2018) prepared a mixed integer programming model to solve the last-mile delivery problem with UAVs for the humanitarian purposes and post disaster action plans. In their research their considered few light weighted items such as vaccines and water purification tablets to be delivered to the affected areas. The model was tested using mixed-integer linear program and solved for different numerically-assumed scenarios (Rabta et al., 2018). Also, Chang and Lee (2018) implemented a non-linear modeling approach to minimize the total distance traveled by the delivery truck and maximize the total coverage area of delivery with UAVs. In their study the main decision variable was the amount of weight loaded on the drone for each shift of delivery operation. Statistical results of their experiment showed a promising effectiveness of their model in comparison with route without shift-weights after K-means clustering and traveling salesman problem modeling, and route by traveling salesman problem for all delivery locations without K-means clustering (Chang & Lee, 2018).

Many of the mentioned studies utilized mathematical based methods to solve complex models rather than finding the exact optimum solution. In this regard, Bouman, Agatz, and Schmidt (2018) suggested an exact solution approach for solving the traveling salesman problem with drones which in comparison with mathematical approaches towards this problem can be implemented on larger scale problems. They also mentioned that applying restrictions on the number of locations which the truck should visit while UAVs are flying, can provide significantly better results in the overall time of delivery and have little effect on solution quality.

Considering whether the combination of the truck and drones are better than selecting one of them and apply the delivery system is one of the challenges which has been addressed by the following study. Ferrandez, Harbison, Weber, Sturges, and Rich (2016) investigated the overall reduction of delivery time and energy for combined UAV and truck delivery system compare to truck or UAV standalone operation. By considering both K-means clustering and traveling salesman problem for their model, they set the objective to minimization of overall cost of delivery. Their findings confirm significant result improvements of integrated UAV and truck delivery system in comparison with standalone system (Ferrandez et al., 2016). In addition, K. Wang, Yuan, Zhao, and Lu (2019) constructed a novel algorithm to solve the traveling salesman problem with drones for the last mile delivery system. Their method considered the managerial perspective about the comprimization of delivery time for the cost effectiveness of the delivery system. Therefore, both delivery time and cost effectivness are taken into account for the objective of their model. A non-dominated sorting generic algorithm was utilized to solve this bi-objective model and results demonestrates high performance validation of the algorithm.

Boysen, Briskorn, Fedtke, and Schwerdfeger (2018) implemented a mixed-integer mathematical approach to solve the truck and UAV delivery system for allocating supply to the customers for the purpose of minimization of total tour duration of UAV delivery. It is good to mentioned that in their study, they distinguished the decisions based on whether a truck should carry several UAVs for landing and take-off or a single UAV (Boysen et al., 2018). Additionally, K. Wang et al. (2019) constructed a novel algorithm to solve the traveling salesman problem with drones for the last mile delivery system. Their method considered the managerial perspective about the comprimization of delivery time for the cost effectiveness of the delivery system. Therefore, both delivery time and cost effectivness are taken into account for the objective of their model. A non-dominated sorting generic algorithm was utilized to solve this bi-objective model and results demonestrates high performance validation of the algorithm. Acoordingly, in this study a novel mathematical model is developed to minimize the maximum delivery time of truck and UAV system in order to cover all the demands and considering the time of take-off and landing of the drones form the truck.

Chapter 3

PROBLEM DEFINITION AND FORMULATION

This chapter is about the methods have been applied in this study, in the previous work (Kangzhou Wang & Wang, 17 Jun 2019.) they didn’t mention specific coordinates as taking off and landing points. we proposed calculation to figure out optimal launching and retrieving point in such a way that minimize the layover time for both truck and drone simultaneously. Also, we tried to put more load on UAV and use the maximum capacity of the UAV battery to reduce the time of satisfying the demands. Because truck and drone models of delivery are relatively new to the academic literature, many papers thus far have studied the case of a single truck and single drone model of delivery, where the drone is capable of carrying only a single homogeneous package at a time. It is frequently assumed that the maximum drone flight duration is constant and does not depend on the weight of any packages to be delivered.

The main difference with the previous work is that we considered a truck and UAV continuous model where UAV is free to satisfy several demand points consecutively, endurance of the UAV is fixed and it is given. We also decoupled the launching and returning points from the demands point (villages) which means the UAV can launch and landed in each point.

3.1 Problem Definition

Consider a disaster such as an earthquake in large rural area there is some demand which are spread through a road (out of main road with no direct way). Our goal is to satisfy all the reachable demand with some specific packages in least time. each package includes some water, blanket, nuts and basic medicines and the weight is less than 5 kg approximately. A truck carrying a UAV delivers parcels in the TSP-D for a list of demand distributed over a road. Each point is visited by either the truck or the UAV, exactly once. Both truck and UAV start from depot and return to the depot (point n+1).

A 3-tuple (i, j, k) is used to denote the drone delivery. node i is a point that we can launch the UAV from the truck. The launch operation spends the time s_L in preparing the delivery. The UAV has passed demand point j and then it will come back to the road at point k. Node k also can be a rendezvous node where the drone rejoins the truck in the case that UAV take off at point p and retrieve at point q. it takes the s_R time to recover the drone. The UAV can launch from depot directly and come back to it after serving last point. This model covers the demand points which do not exceed from the UAV capacity. When the UAV is out of service and it does not perform the delivery, it is transferred by the truck. By the same time truck can go and serve the demand which are near to the main road. Maybe they have to wait for each other at meeting point and the UAV supposed to be in continues flight while is waiting for the truck at the rendezvous point. A tuple (i, j, k) is feasible where the total time needed to visit node j from node i, the time required to reach node k from node j, and the waiting time at node k does not exceed the drone's endurance or maximum flying time. This is assumed that in each meet the UAV battery will replace by truck.

The goal of the objective TSP-D is to find the coordinated of launching and retrieving points for the UAV with the minimizing completion time. The completion time is the latest time at which either the truck or the drone returns to the depot.

In order to formulate the problem, we define the notation: V = {0, 1,..., n, n+1} is the set of node in which 0 and n + 1 denote the depot and n is the number of demand points; V_L = {0,1, ... , n} and V_R = {1,2, ... , n + 1} are the nodes from which the drone is launched and to which it returns, respectively; V_D is the set of demand points that can be served by the UAV; d_{ij} and d_{ij}' are the distances from nodes i to j travelled by the truck and the UAV, respectively; τ_{ij} and τ_{ij}' are the travel times from nodes i to j of the truck and the drone, respectively; ε is the flight endurance of the drone; P ={(i, j, k): $i \in V_L, j \in V_D, k \in V_R, i \neq j, j \neq k, k \neq i, \tau_{ij}' + \tau_{jk}' \leq \varepsilon$} is the set of all possible tuples that may be flown by the drone; and M is a sufficiently large number.

Decision variables are specified in the model: x_{ij} is a binary decision variable equivalent to 1 if the truck runs from nodes i to j and 0 otherwise; y_{ijk} is a binary decision variable equivalent to 1 if the tuple (i, j, k) ∈{(i, j, k)): i, j, k ∈ V } is selected in the solution and 0 otherwise; p_{ij} is a binary decision variable equivalent to 1 if the node i is visited before j and 0 otherwise; u_i is the location of the node i in the truck route; t_i and t_i' are the arrival times of the truck and the UAV on the node i r_i and r_i' are the departure times of the truck and the UAV on the node i, same to the Murray and Chu (2015) and Ha et al. (2018) models, the proposed problem is formulated as:

Min $f_t = \max(t_{n+1}; t'_{n+1})$ (1)

Objective function is (1) to minimize the process time .

s.t. $\sum_{i\in v_L} x_{ij} + \sum_{(i,j,k)\in p} y_{ijk} = 1 \qquad \forall j \in N \qquad (2)$

Constraints (2) specify that each demand point is approached by either a vehicle or a drone once:

$\sum_{j\in v_R} x_{0j} = 1 \qquad (3)$

$\sum_{i\in v_L} x_{i,n+1} = 1 \qquad (4)$

$\sum_{j\in v_L} x_{ij} - \sum_{j\in v_R} x_{ji} = 0 \qquad \forall j \in N \qquad (5)$

Constraints (3)–(5) explains tour of the truck which departs from the warehouse, visits the allocated nodes, and returns to the warehouse again.

$\sum_{(i,j,k)\in p} y_{ijk} \le 1 \qquad \forall i \in v_L \qquad (6)$

$\sum_{(i,j,k)\in p} y_{ijk} \le 1 \qquad \forall k \in v_R \qquad (7)$

Constraints (6)–(7) guarantee that each node can launch (or retrieve) a drone maximum one time.

$2\, y_{ijk} \le \sum_{h\in v_L} x_{hi} + \sum_{h\in N} x_{hk} \qquad \forall (i,j,k) \in p \qquad (8)$

$y_{0jk} \le \sum_{h\in v_L} x_{hk} \qquad \forall (0,j,k) \in p \qquad (9)$

Constraints (8) and (9) explain the relationship between variables.

$u_i - u_j + 1 \le (n+2).(1 - x_{ij}) \qquad \forall i \in v_L, j \in \{v_R: j \neq i\} \quad (10)$

$u_i - u_j \ge 1 - (n+2).(1 - \sum_{j\in N} y_{ijk}) \qquad \forall i \in v_L, k \in \{v_R: k \neq i\} \quad (11)$

$u_i - u_j \ge 1 - (n+2).p_{ij} - M.(2 - \sum_{h\in v_L} x_{hi} - \sum_{h\in N} x_{hj}) \quad \forall i \in N, j \in \{v_R: j \neq i\} \quad (12)$

$u_i - u_j \le -1 + (n+2).(1 - p_{ij}) + M.(2 - \sum_{h\in v_L} x_{hi} - \sum_{h\in N} x_{hj}) \; \forall i \in N, j \in \{vR: j \neq i\} \; (13)$

$u_0 - u_j \ge 1 - (n+2).p_{0j} - M.(1 - \sum_{h\in v_L} x_{hj}) \qquad \forall j \in v_R \qquad (14)$

$u_0 - u_j \le -1 + (n+2).(1 - p_{0j}) + M.(1 - \sum_{h\in v_L} x_{hj}) \qquad \forall j \in v_R \qquad (15)$

$u_l \ge u_k - M.\left(3 - \sum_{j\in\{N: j\neq 1\}} y_{ijk} - \sum_{m\in\{N: m\neq i,k,l\}} \sum_{h\in\{v_R: h\neq i,k\}} y_{lmh} - p_{il}\right)$

$\forall i \in v_L, k \in \{v_R: k \neq i\}, l \in \{N: l \neq i, l \neq k\} \qquad (16)$

Constraints (10)-(16) ensure the precedence relations between the nodes.

$t_k \ge r_i + \tau_{ik} - M.(1 - x_{ik}) \qquad \forall i \in v_L, k \in \{v_R: k \neq i\} \quad (17)$

$t_k \leq r_i + \tau_{ik} + M.(1 - x_{ik})$ $\forall i \in v_L, k \in \{v_R: k \neq i\}$ (18)

$t'_j \geq r_i + \tau'_{ij} - M.(1 - \sum_{(i,j,k)\in p} y_{ijk})$ $\forall i \in v_L, j \in \{v_D: j \neq i\}$ (19)

$t'_j \leq r_i + \tau'_{ij} + M.(1 - \sum_{(i,j,k)\in p} y_{ijk})$ $\forall i \in v_L, j \in \{v_D: j \neq i\}$ (20)

$t'_k \geq r'_j + \tau'_{jk} - M.(1 - \sum_{(i,j,k)\in p} y_{ijk})$ $\forall j \in v_D, k \in \{v_R: k \neq j\}$ (21)

$t'_k \leq r'_j + \tau'_{jk} + M.(1 - \sum_{(i,j,k)\in p} y_{ijk})$ $\forall j \in v_D, k \in \{v_R: k \neq j\}$ (22)

$t'_j \geq r'_j - M.(1 - \sum_{(i,j,k)\in p} y_{ijk})$ $\forall j \in N$ (23)

$t'_j \leq r'_j + M.(1 - \sum_{(i,j,k)\in p} y_{ijk})$ $\forall j \in N$ (24)

$r_k \geq t_k + s_L \sum_{(k,l,m)\in p} y_{klm} + s_R \sum_{(i,j,k)\in p} y_{ijk} - M.(1 - \sum_{(i,j,k)\in p} y_{ijk})$ $\forall k \in v_R$ (25)

$r'_k \geq t'_k + s_L \sum_{(k,l,m)\in p} y_{klm} + s_R \sum_{(i,j,k)\in p} y_{ijk} - M.(1 - \sum_{(i,j,k)\in p} y_{ijk})$ $\forall k \in v_R$ (26)

$r_i = r'_i$ $\forall i \in V$ (27)

Constraints (17)- (27) Arrival and departure time calculations.

$r'_k - (r'_j + \tau'_{ij}) - s_L.\sum_{(k,l,m)\in p} y_{klm} \leq \varepsilon + M.(1 - y_{ijk})$ $\forall (i,j,k) \in p$ (28)

This constraint represent that the flying time of UAV shouldn't be more than endurance.

$t_0 = 0, t'_0 = 0, r_0 = 0, r'_0 = 0$ (29)

$x_{ij} \in \{0,1\}$ $\forall i \in v_L, j \in \{v_R: j \neq i\}$ (30)

$x_{ii} = 0$ $\forall i \in V$ (31)

$y_{ijk} \in \{0,1\}$ $\forall (i,j,k) \in p$ (32)

$y_{ijk} = 0$ $\forall (i,j,k) \in \{(i,j,k): i,j,k \in V, (i,j,k) \notin p\}$ (33)

$p_{ij} \in \{0,1\}$ $\forall i,j \in \{N: j \neq\}$ (34)

$p_{ii} = 0$ $\forall i \in N$ (35)

$p_{0j} = 1$ $\forall j \in N$ (36)

$0 \leq u_i \leq n + 1$ $\forall i \in V$ (37)

$t_i, t'_i, r_i, r'_i, \geq 0$ $\forall i \in V$ (38)

Constraints (29)-(38) Domain definition of the variable

3.2 Solution Approach

With the minimization of either completion time (Murray & Chu, 2015) or operational cost (Ha et al., 2018), the mathematical model for the TSP-D cannot solve instances with 11 points or more to optimum in less than an hour . A collection of solutions is required for these kinds of optimization problems, and it is impossible to solve the model in a reasonable time to obtain such solutions. Given its intractability, we therefore wrote a program to find the launch and return point of UAV in case of satisfying 3 demand points individually or in a group tour in order to minimize the travelled distance.

In this part we exactly calculated the optimal launching and retrieve point of UAV in one truck and one drone system which has indirect effect on overall time deduction, in other worlds, the higher speed vehicles which is UAV mostly will go as much as it can in such a way that the UAV and the truck move simultaneously in order to minimize the total process time consumed, this combination has not received enough attention before.

We prepared equation below to found out the launching and retrieving point in order to minimize the waiting time for both vehicle and UAV.

Consider m as the vertical distance of the demand point from the road, p is the launching point and q is the retrieving point, w is the speed of UAV and v is the truck speed. We assumed that w is strictly greater than v.

$$\frac{\sqrt{m^2 + p^2}}{w} + \frac{\sqrt{m^2 + q^2}}{w} = \frac{q - p}{v}$$

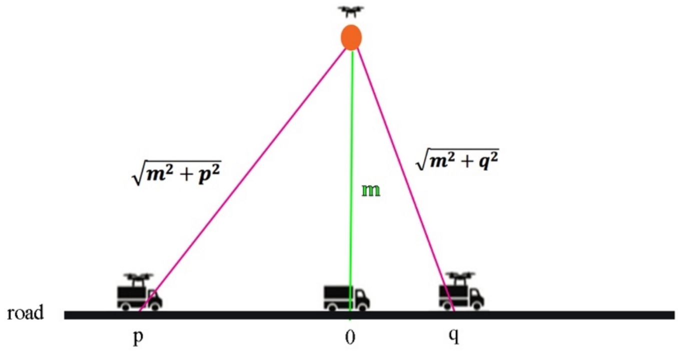

Figure 3.1: Launching and returning point of UAV

On the left part of equation is travelled distance by UAV over its speed, and the right side is distance which truck travelled over truck speed. Because the both sides are in the time term we putted them equal to take out the layover time from model.

Editor – /Users/appleonline/Documents/MATLAB/untitled.m*

untitled.m*

```
clc; clear

syms q p v w m
eqn = (m^2 + p^2)^(1/2)/w + (m^2 + q^2)^(1/2)/w == ((q - p)/v);
qvalue = solve(eqn,q)
```

Figure 3.2: Calculation code in MATLAB

Command Window

```
qvalue =

                                                     p
 -(p*v^2 + p*w^2 + 2*v*w*(m^2 + p^2)^(1/2))/(v^2 - w^2)
```

Figure 3.3: Optimal q value

By using MATLAB, we solved the equation above in term of q and got the following value for q.

$$q = -\frac{\left(pv^2 + pw^2 + 2vw\sqrt{m^2 + p^2}\right)}{v^2 - w^2}$$

```
Command Window

equation1 =

-(p + (p*v^2 + p*w^2 + 2*v*w*(m^2 + p^2)^(1/2))/(v^2 - w^2))/v
```

Figure 3.4: Substitution of q in equation

Again we substituted the q value on the right part of first equation ($\frac{\boldsymbol{q-p}}{\boldsymbol{v}}$), then all the variables would be in term of p. Since there is no q in the equation anymore, we could calculate the optimal value for p by differentiating the equation in term of p and got values below.

$$\frac{\left[-\frac{2vw\sqrt{m^2+p^2}+p(v^2+w^2)}{v^2-w^2}-p\right]}{v}$$

$$\frac{\partial f}{\partial p}=-\frac{\left[p(v^2-w^2)+2vw\sqrt{m^2+p^2}+P(v^2+w^2)\right]}{v(v^2-w^2)}$$

$$\frac{\partial f}{\partial p}=-\frac{2v}{v^2-w^2}p-\frac{2w\sqrt{m^2+p^2}}{v^2-w^2}$$

Now put this equation equal to zero to find the optimal value for p $\rightarrow f'=\frac{\partial f}{\partial p}=0$

$$\frac{\partial f}{\partial p}=-\frac{2\left(v\sqrt{m^2+p^2}+wp\right)}{(v^2-w^2)\sqrt{m^2+p^2}}=0$$

$$v(\sqrt{m^2+p^2}+wp=0$$

$$v^{2(m^2+p^2)}=w^2p^2$$

$$p^2(w^2-v^2)=v^2m^2$$

$$P=\pm\frac{vm}{\sqrt{w^2+v^2}}$$

P got positive and mines values the positive one is retrieving point and the negative one is the launching point; we also knew this from before that the optimality for p value will occurs somewhere which p and q get the same values.

We provide formulation below to ensure that the travelling time of the UAV will not exceed from the remaining endurance so, E is defined as remaining endurance, W also defined as speed of UAV, a as launching and b as retrieving point.

$$\sqrt{m^2 + a^2} + \sqrt{m^2 + b^2} = WE$$

$$m^2 + a^2 + m^2 + b^2 + 2\sqrt{(m^2 + a^2)(m^2 + b^2)} = W^2E^2$$

$$\sqrt{(m^2 + a^2)(m^2 + b^2)} = \frac{W^2E^2 - a^2 - b^2 - 2m^2}{2}$$

$$(m^2 + a^2)(m^2 + b^2) = \frac{(W^2E^2 - a^2 - b^2 - 2m^2)^2}{4}$$

$$4(m^4 + m^2(a^2 + b^2) + a^2b^2) = (W^2E^2 - a^2 - b^2 - 2m^2)^2$$

$$4\cancel{m^4} + 4\cancel{a^2m^2} + 4\cancel{b^2m^2} + 4\cancel{a^2b^2}$$

$$= W^4E^4 + a^4 + b^4 + 4\cancel{m^4} - 2W^2E^2a^2 - 2W^2E^2b^2 - 4W^2E^2m^2$$

$$+ \cancel{2a^2b^2} + 4\cancel{a^2m^2} + 4\cancel{b^2m^2}$$

$$2a^2b^2 - b^4 + 2W^2E^2b^2 = W^4E^4 + a^4 - 2W^2E^2a^2 - 4W^2E^2m^2$$

$$W^4E^4 + a^4 - 2W^2E^2a^2 - 4W^2E^2m^2 = \overline{C}$$

$$B = b^2 \geq m^2 \geq 0$$

$$B^2 - (2a^2 + 2W^2E^2)B + \overline{C} = 0$$

$$B_{1,2} = a^2 + W^2E^2 \pm \sqrt{(a^2 + W^2E^2)^2 - \overline{C}}$$

$$\cancel{a^4} + \cancel{W^4E^4} + 2W^2E^2a^2 - \cancel{W^4E^4} - \cancel{a^4} + 2W^2E^2a^2 + 4W^2E^2m^2$$

$$= 4W^2E^2a^2 + 4W^2E^2m^2$$

$$\Longrightarrow B_{1,2} = a^4 + W^2E^2 \pm 2WE\sqrt{m^2 + a^2} \geq m^2$$

In other world we can interpret the formulations above like following figure:

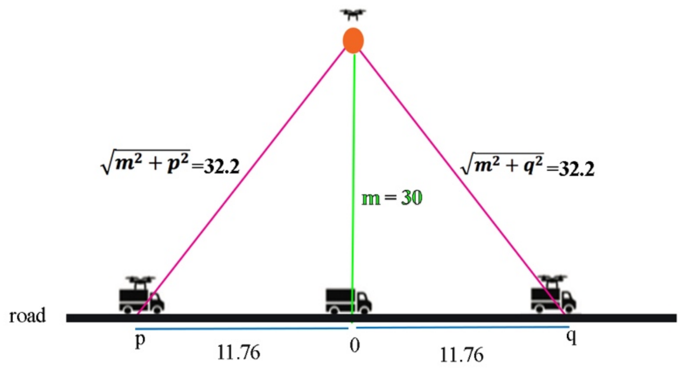

Figure 3.5: Graphical representation of the model

In this example m (30km) is given through the UAV (220km/h) and truck (80km/h) speed we can calculate the p and q and the UAV travelling distance afterward.

The flying time for UAV and truck is:

$$t = \frac{\sqrt{m^2 + p^2}}{w} + \frac{\sqrt{m^2 + q^2}}{w} = \frac{32.2}{220} + \frac{32.2}{220} = 0.29$$

If we change the launching point from 11.76 km to 6 km UAV travelling time will changes as follow:

$$t = \frac{\sqrt{m^2 + p^2}}{w} + \frac{\sqrt{m^2 + q^2}}{w} = \frac{\sqrt{6^2 + 30^2}}{220} + \frac{32.2}{220} = 0.28$$

But the truck will reach to the rendezvous sooner than UAV.

$$t = \frac{q - p}{v} = \frac{11.76 - (-6)}{80} = 0.22$$

For address this problem in python programming we assume that the coordinates of the demand points and the roads are given so we define N as the total number of demand points, d_i as demand of point i, Q as payload of UAV and Q_r as remaining payload. Ɛ epsilon as the endurance of UAV and $Ɛ_r$ remaining endurance. W as UAV speed and V as truck speed. S as distance between two neighbor demand points, e.g. $S_{i,i+1}$ is the distance between points i and i+1 and we also define $S_{i,r}$ to consider the distance for going back from point i to the road.

Algorithm:

Set Q_r as maximum payload, and $Ɛ_r$ as maximum endurance,

while $Ɛ_r*W >= S_{i,i+1} + S_{i+1,r}$ *and* $i<N$ *do*

if $d_{i+1} <= Q_r\ (Q-\sum_{i=1}^{i} d\ i)$ *then*

Go to the next demand point (i+1)

Update the set of satisfied points: current point (i+1) $\cup$ set of satisfied points.

Update the value of Q_r and $Ɛ_r$

else

go back to the truck from point i

i+=1

end

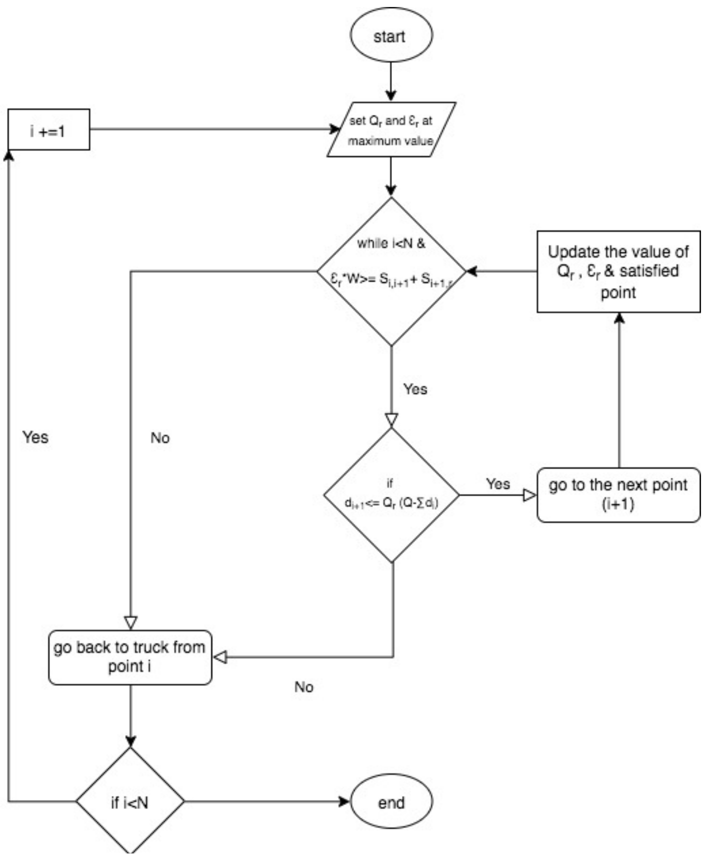

Figure 3.6: Program flowchart

Chapter 4

CASE STUDY ON NEPAL

In April 2015 a 7.8 Richter scale earthquake destroyed hundreds of villages and roads in Nepal, killed over 9,000 people and injured nearly 22,000. The earthquake in Kathmandu, Nepal, had two aftershocks on 12 May by magnitude of 7.3 and 6.7 M_w which also caused people losses. Nepal is located in a seismically active zone and there are numerous faults in this region of the world. In this part of the world which covers the first of the Eurasian Plate, the two India and Eurasia Continental planes meet, causing it to shift up to four inches per year. The tension of the planes on 2,000 km of land puts a lot of pressure on the ground's lower layers, which triggered an earthquake in Nepal and the Himalayas. The recent computer modelling of Swiss researchers suggests that the friction between India and Eurasia near the Himalayas can cause an earthquake with more power than 8.1 on the Richter scale and must already be made to deal with the dangers of such a deadly earthquake. So, we consider Nepal area as a case study through the given demand points and available roads after disaster via Schiebel UAV with information below.

PERFORMANCE | TECHNICAL

Maximum airspeed (V_{NE})	130 kn (240 km/h) IAS
Dash speed	120 kn (222 km/h) IAS
Loiter speed	55 kn IAS (102 km/h) for maximum endurance
Endurance	>6 h with 34 kg (75 lbs) payload plus optional external fuel tank extending endurance to >10 h
Service ceiling	18000 ft in ISA conditions @ reduced GW
Airframe loading	+3.5 g to -1 g rated
Operating temperature	-40°C to +55°C (-40°F to +131°F)
Wind (takeoff and landing)	Up to 25 kn (46 km/h)

PERFORMANCE | TECHNICAL

Main rotor diameter	3400 mm (133.9")
Total length	3110 mm (122")
Total height	1120 mm (44")
MTO weight	200 kg (440 lbs)
Empty weight	110 kg (243 lbs)
Payload capacity	50 kg (110 lbs)
Fuel (internal tanks)	57 l (15.0 gal) AVGAS 100LL, JP-5 (NATO F-44), Jet A-1 (NATO F-35)
Payload electrical power	1000 W @ 24 V DC
Data link range	Up to 200 km (108 nm) available

Figure 4.1: UAV specifications

Endurance of UAV is 6 hour which we reduce it to 5 hours to eliminate the wind and different altitude effect. Maximum payload is 50 kg so it can carry on between 7 to 10 packages in each tour.

Note: all the calculations were done on the scale of 10 km. (1km on the map =10km)

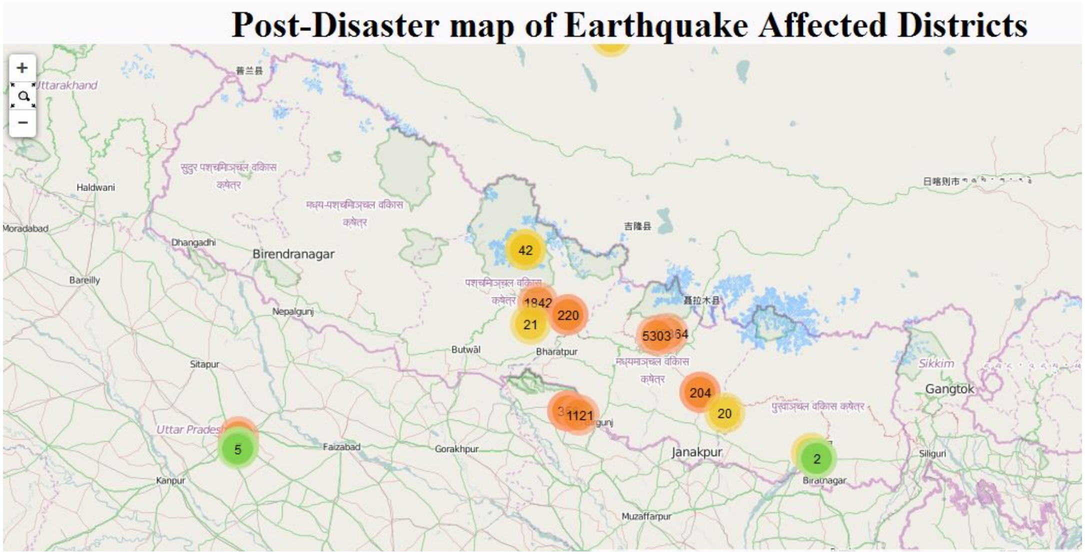

Figure 4.2: Post-disaster demand points (Nepal earthquakes 2015)

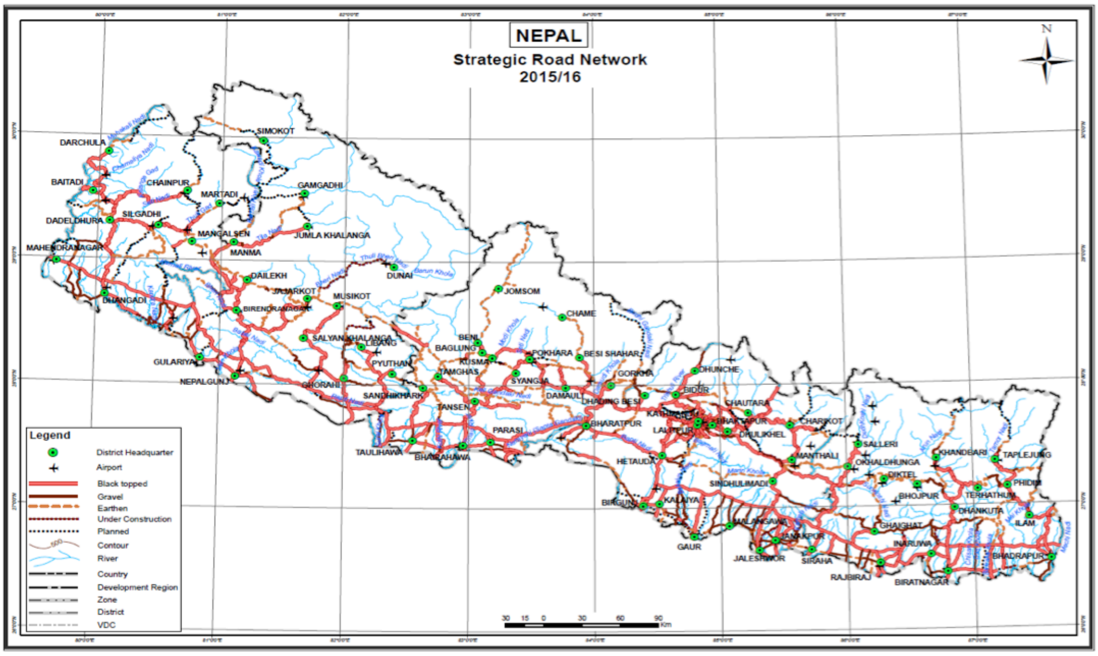

Figure 4.3: Roads map of NEPAL 2015

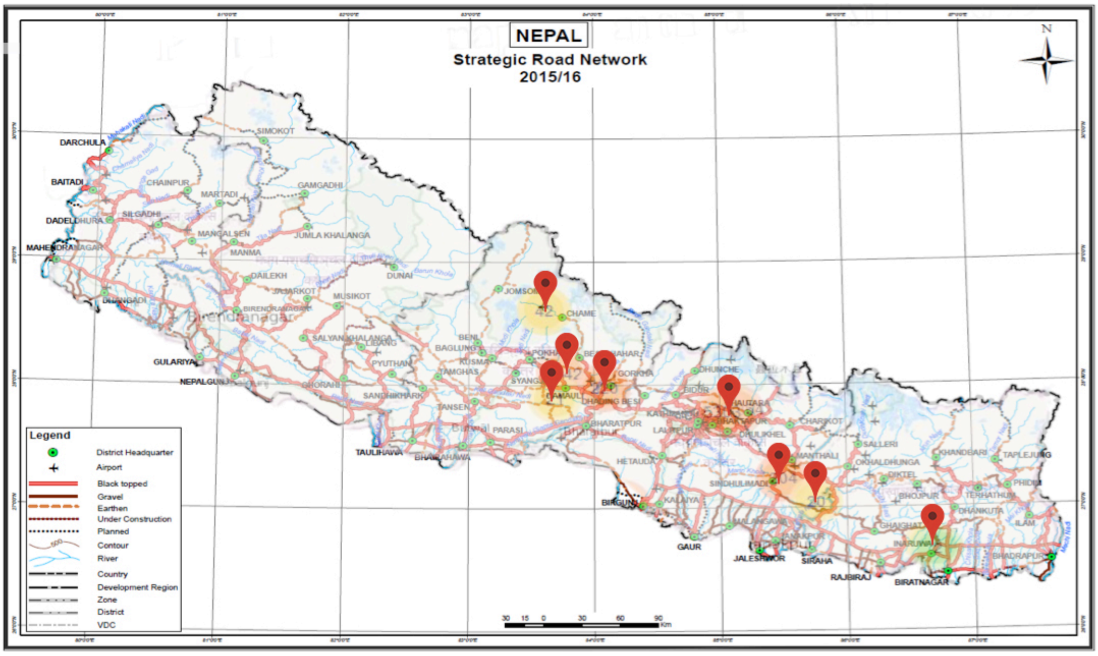

Figure 4.4: Demands point on the roads map

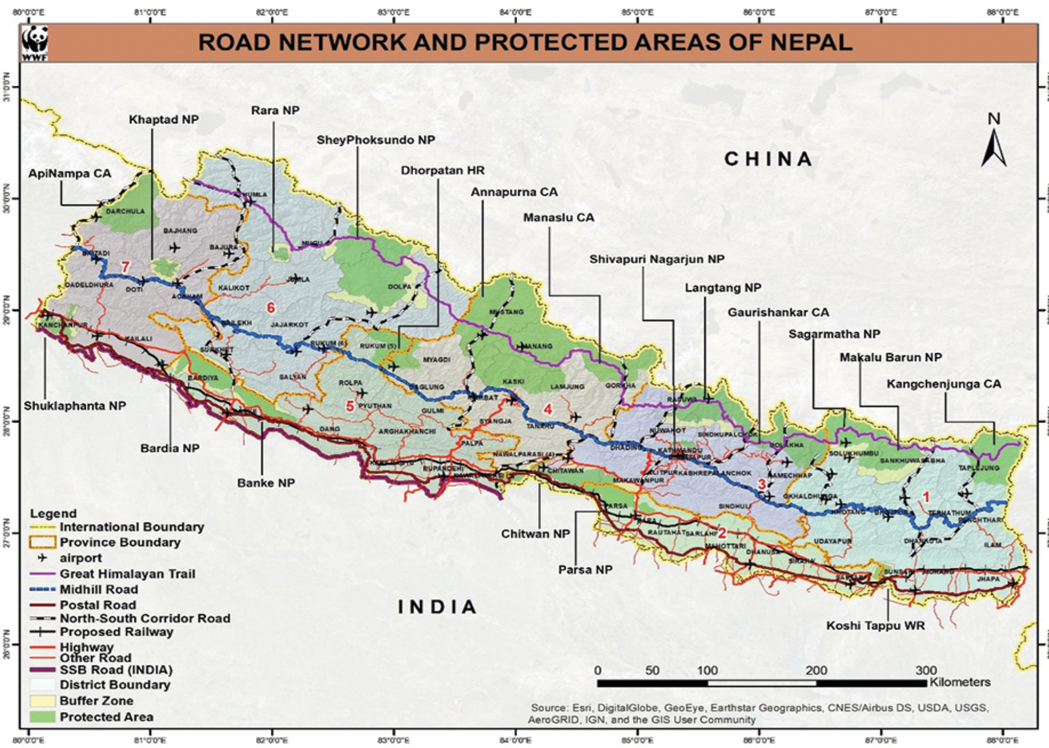

Figure 4.5: Roads map supposed to be complete in 2021

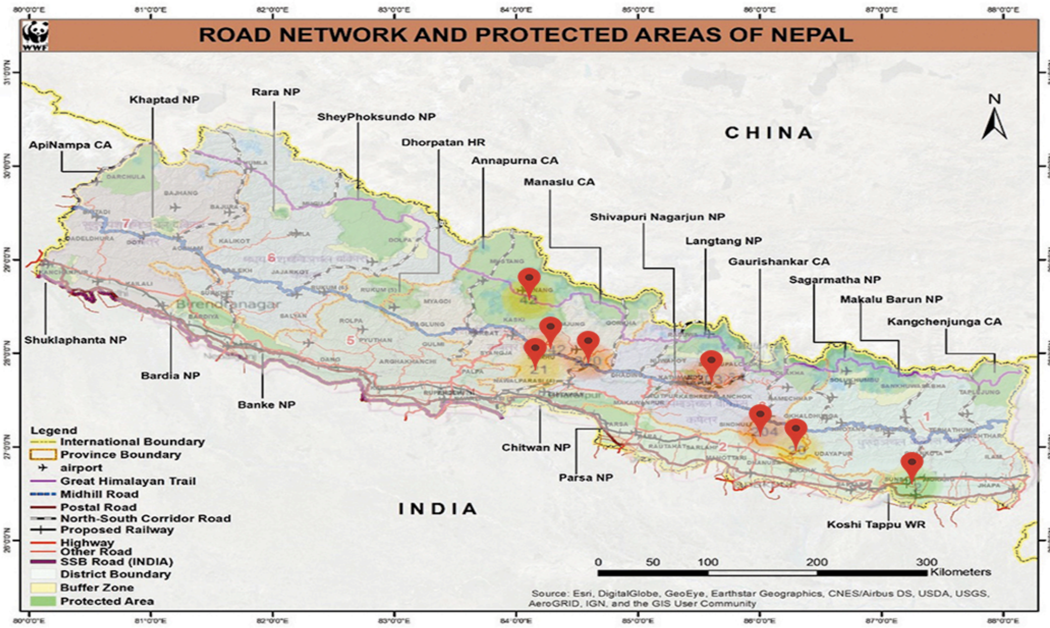

Figure 4.6: Demand points on the new roads map

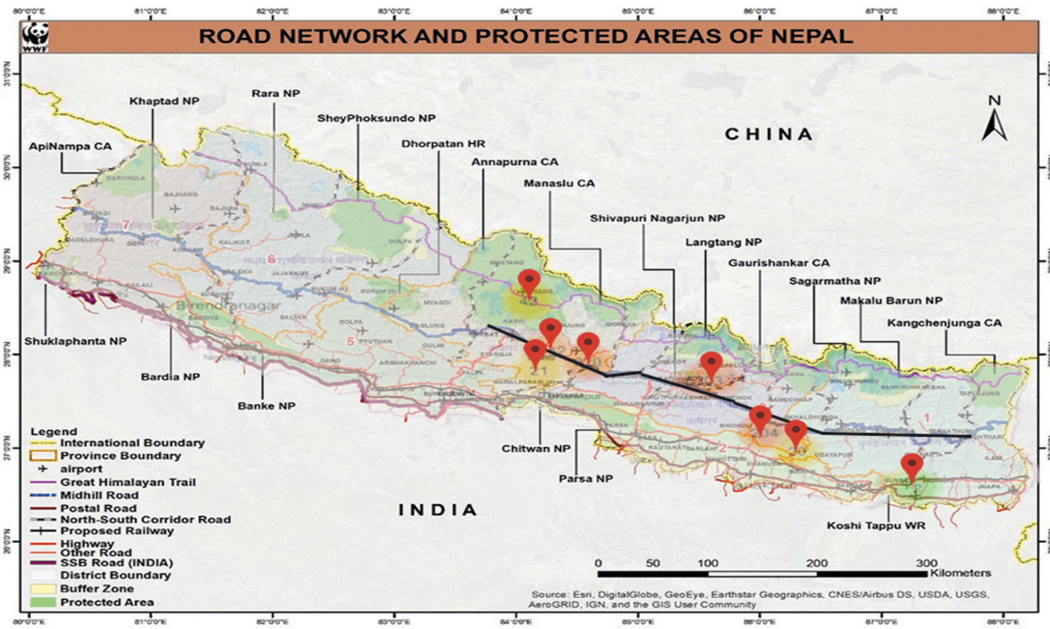

Figure 4.7: Linear approximation of roads

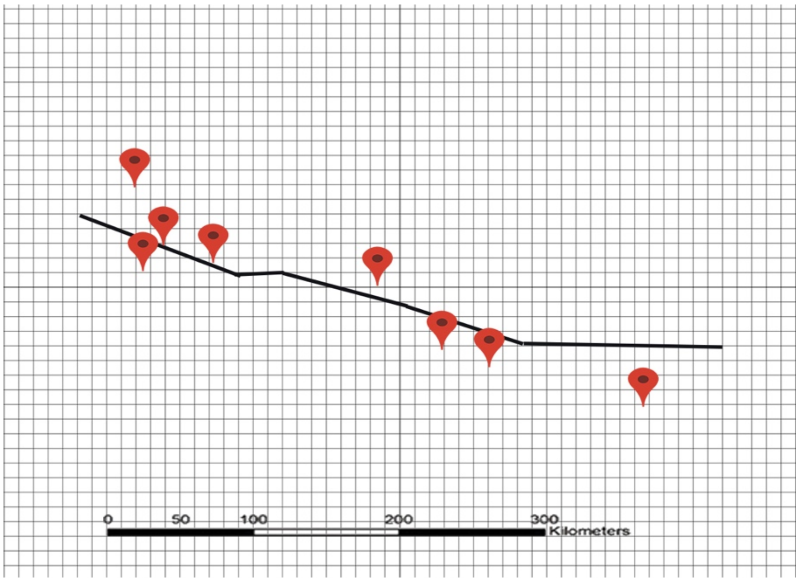

Figure 4.8: Roads and given demand on the coordinates chart

Demand points which are on road would be eliminated from the set of demand point since they will be satisfied by truck.

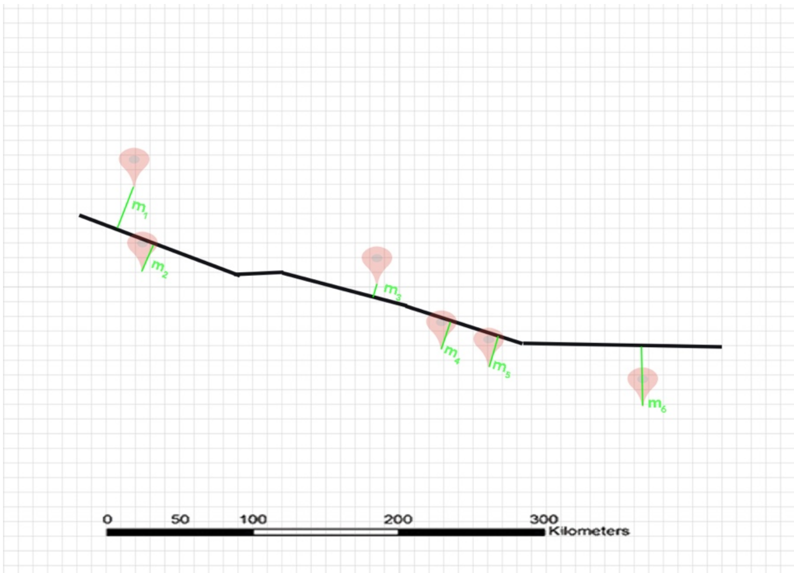

Figure 4.9: Defined m as distance between demand points and road

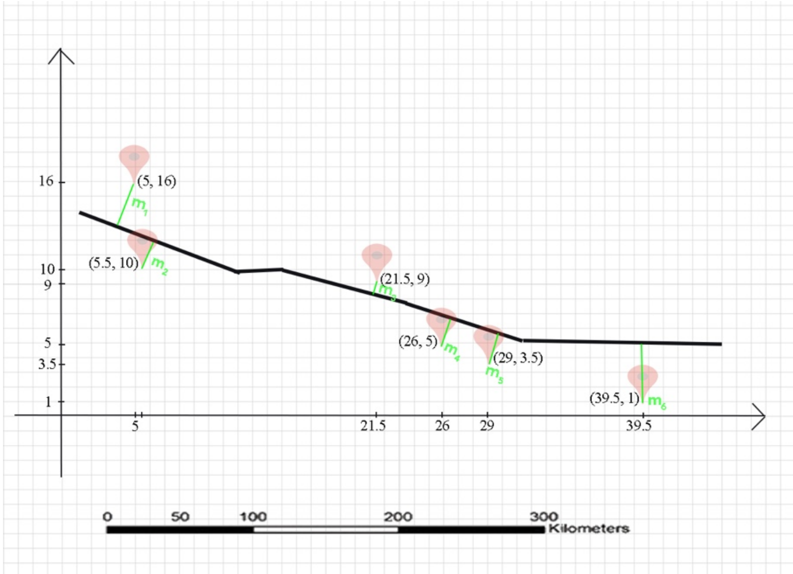

Figure 4.10: Coordinates of demand points

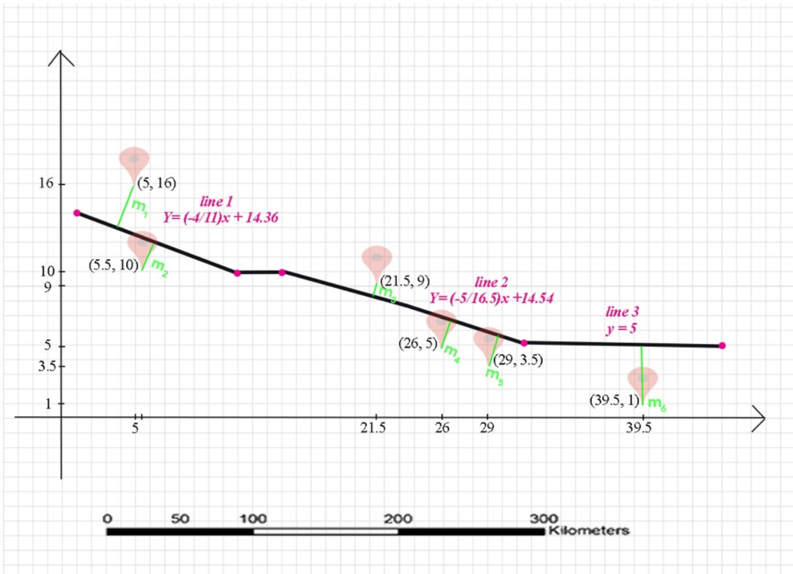

Figure 4.11: Determined lines equations

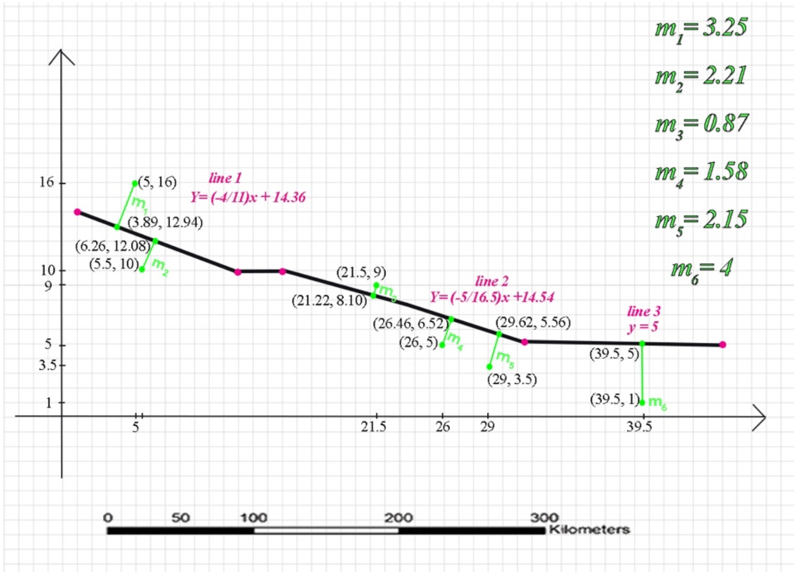

Figure 4.12: Demands and road cross points and line equations

4.1 Computational Results

Table 4.1: Software results

Demand point	Demand on road	m_i	p_i	Launch point	Retrieve point
5.0,16.0	03.889,12.946	3.25	1.26	2.83,13.331	4.948,12.561
5.5,10.0	06.258,12.084	2.21	0.86	5.383,12.403	7.133,11.766
21.5,9.0	21.229,8.107	0.93	0.36	20.652,8.282	21.806,7.932
26.0,5.0	26.461,6.522	1.59	0.62	25.707,6.750	27.215,6.293
29.0,3.5	29.625,5.563	2.15	0.84	28.747,5.829	30.503,5.297
39.5,1.0	39.500,5.000	4.00	1.56	38.251,5.000	40.749,5.000

Application calculated all the launching and retrieving points. Since they don't have any intersection to each other we can launch the UAV with the coordinates gained from application and the total process time would be equal to 5 hours and 40 minutes. And it's completely connected to the truck speed:

- Length of line1: $\sqrt{4^2 + 11^2} = \sqrt{137} = 11.7$km
- Length of line2: 3km
- Length of line3: $\sqrt{6^2 + 16.5^2} = \sqrt{297.25} = 17.24$km
- Length of line4: 13.5km
- Total travelled distance by truck 45.44 km by speed of 80 km per hour.

4.2 Numeric Data and Comparison Between Combined Cases

```
[[5.0, 16.0], [3.889, 12.946], 3.25, 1.269, [2.83, 13.331
], [4.948, 12.561]]
[[5.5, 10.0], [6.258, 12.084], 2.218, 0.866, [5.383, 12.403
], [7.133, 11.766]]
[[21.5, 9.0], [21.229, 8.107], 0.933, 0.364, [20.652, 8.282
], [21.806, 7.932]]
[[26.0, 5.0], [26.461, 6.522], 1.59, 0.621, [25.707, 6.75
], [27.215, 6.293]]
[[29.0, 3.5], [29.625, 5.563], 2.156, 0.842, [28.747, 5.829
], [30.503, 5.297]]
[[39.5, 1.0], [39.5, 5.0], 4.0, 1.561, [38.251, 5.0], [40.
749, 5.0]]


Individually Launch 1
Launch 1: 3.44 , Retrieve 1 : 3.44
>>> Sum : 6.88

Combination Launch 1 and 2
Launch 1: 3.44  Launch 1 to 2: 2.716    Retrieve 2: 2.406
>>> Sum : 8.562

Combination Launch 1 , 2 and 3
Launch 1: 3.44  Launch 1 to 2: 2.716    Launch 2 to 3: 15.
815     Retrieve 3: 1.111
>>> Sum : 23.082
==================
Individually Launch 2
Launch 2: 2.406 , Retrieve 2 : 2.406
>>> Sum : 4.812

Combination Launch 2 and 3
Launch 2: 2.406     Launch 2 to 3: 15.815   Retrieve 3: 1.
111
>>> Sum : 19.332

Combination Launch 2 , 3 and 4
Launch 2: 2.406     Launch 2 to 3: 15.815   Launch 3 to 4:
5.282   Retrieve 4: 1.774
>>> Sum : 25.277
==================
Individually Launch 3
Launch 3: 1.111 , Retrieve 3 : 1.111
>>> Sum : 2.222

Combination Launch 3 and 4
```

Figure 4.13: Python results

```
Launch 3: 1.111     Launch 3 to 4: 5.282    Retrieve 4: 1.774
>>> Sum : 8.167

Combination Launch 3 , 4 and 5
Launch 3: 1.111     Launch 3 to 4: 5.282    Launch 4 to 5: 3.176   Retrieve 5: 2.343
>>> Sum : 11.912
==================
Individually Launch 4
Launch 4: 1.774 , Retrieve 4 : 1.774
>>> Sum : 3.548

Combination Launch 4 and 5
Launch 4: 1.774     Launch 4 to 5: 3.176    Retrieve 5: 2.343
>>> Sum : 7.293

Combination Launch 4 , 5 and 6
Launch 4: 1.774     Launch 4 to 5: 3.176    Launch 5 to 6: 9.54    Retrieve 6: 4.19
>>> Sum : 18.68
==================
Individually Launch 5
Launch 5: 2.343 , Retrieve 5 : 2.343
>>> Sum : 4.686

Combination Launch 5 and 6
Launch 5: 2.343     Launch 5 to 6: 9.54     Retrieve 6: 4.19
>>> Sum : 16.073
==================
Individually Launch 6
Launch 6: 4.19 , Retrieve 6 : 4.19
==================

Process finished with exit code 0

```

Figure 4.14: Python results

Table 4.2: Cumulative travelled distance in km

To / From	1	2	3	4	5	6
1	6.88	8.562	23.082			
2		4.812	19.332	25.277		
3			2.222	8.167	11.912	
4				3.548	7.293	18.68
5					4.686	16.073
6						8.38

Optimal set{{1, 2}, {3}, {4, 5}, {6}} in the case of combined launch. Combined tour for demand 1 and 2, individual tour for 3, combined tour for 4 and 5 and individual tour for 6.

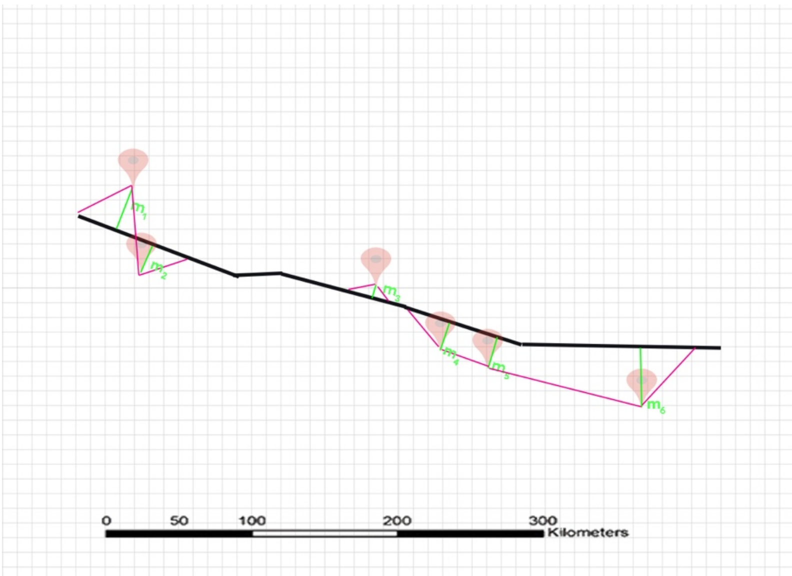

Figure 4.15: Possible flight No.1

Sum of travelled distance by UAV= 29.462

Figure 4.16: Possible flight No.2

Sum of travelled distance by UAV= 26.457

Chapter 5

CONCLUSION AND FUTURE STUDIES

In this study we considered one truck and one UAV, wrote the mathematical model for hybrid routing truck and UAV, in addition launch and retrieve points are calculated, and then applied the Nepal case study with certain demands point and given road equations to the program and we got the results, its obvious that when above mentioned demands regarding UAV are satisfied in a successive tour , this will ease and reduce the distance travelled.

Based on results which we discussed in previous chapter we got better results by fulfil the neighboring demand in one tour (in the case that we have enough loaded packages on UAV and the endurance is big enough to come back to the road (truck) after satisfying the demand).

The potentials of drones are noticed in many developing international companies testing as practical class usages. However, UAV are associated with a basic limitation among which includes limited loadable product and flight duration time. As such, this weakness of UAV has hindered the limit of UAV usage which lead to the proposed use of trucks and UAV. This will be possible via the launching of UAV from a truck to the desired location and ultimately returning the drone back to the truck. This process will ease and relaxed restrictions for UAV when it comes to traveling and sharing its delivery with a truck.

Several future research exists for the proposed study, considering this study, the exchange of batteries time was supposed to be fixed and included in the rendezvous and launching time or considering the demand points near the roads cross and calculate optimal launching point for them. furthermore, considering the dynamic battery charging and its energy consumption, more realistic and suitable routing schedules will be provided via its optimization by extending single truck and drones cases to several vehicles and drones respectively. Furthermore, there is room for exploring the problems associated with different shapes of scales in prohibited zones and finding other flight detour accordingly, also with consideration to different objectives functions, this might be an interesting topic conflicting criterion handling in the system.

REFERENCES

Adams, S., & Friedland, C. (2011). *A survey of unmanned aerial vehicle (UAV) usage for imagery collection in disaster research and management*. 9th International Workshop on Remote Sensing for Disaster Response.

Axel, C. (2017). *Towards Automated Analysis of Urban Infrastructure after Natural Disasters using Remote Sensing*: Rochester Institute of Technology.

Bouman, P., Agatz, N., & Schmidt, M. (2018). Dynamic programming approaches for the traveling salesman problem with drone. *Networks, 72*(4), 528-542.

Boysen, N., Briskorn, D., Fedtke, S., & Schwerdfeger, S. (2018). Drone delivery from trucks: Drone scheduling for given truck routes. *Networks, 72*(4), 506-527.

Camacho-Vallejo, J. F., Gonzalez-Rodriguez, E., Almaguer, F. J., & Gonzalez-Ramirez, R. G. (2015). A bi-level optimization model for aid distribution after the occurrence of a disaster. *Journal of Cleaner Production, 105*, 134-145. doi:10.1016/j.jclepro.2014.09.069

Caunhye, A. M., Nie, X., & Pokharel, S. (2012). Optimization models in emergency logistics: A literature review. *Socio-economic planning sciences, 46*(1), 4-13.

Chand, M. (2018). Effective usage of unmanned aerial vehicle technology in emergency operations in Canada.

Chang, Y. S., & Lee, H. J. (2018). Optimal delivery routing with wider drone-delivery areas along a shorter truck-route. *Expert Systems with Applications, 104*, 307-317.

Chauhan, D., Unnikrishnan, A., & Figliozzi, M. (2019). Maximum coverage capacitated facility location problem with range constrained drones. *Transportation Research Part C: Emerging Technologies, 99*, 1-18.

Chen, Y., Zhang, H., & Xu, M. (2014). *The coverage problem in UAV network: A survey.* Paper presented at the Fifth International Conference on Computing, Communications and Networking Technologies (ICCCNT).

Chowdhury, S. (2018). *Drone routing and optimization for post-disaster inspection*: Mississippi State University.

De Oliveira Silva, L., de Mello Bandeira, R. A., & Campos, V. B. G. (2017). The use of UAV and geographic information systems for facility location in a post-disaster scenario. *Transportation research procedia, 27*, 1137-1145.

De Oliveira Silva, L., de Mello Bandeira, R. A., & Campos, V. B. G. (2019). Proposal to planning facility location using UAV and geographic information systems in a post-disaster scenario. *International Journal of Disaster Risk Reduction, 36*, 101080.

Durga, N. (2011). *Situation Awareness in Multiple Unmanned Aerial Vehicle Control.* San Jose State University, Ellis, R., & Newsome, J. (April 2, 2018). *Drone, social media make flood rescue happen in real time*. https://www.cnn.com/ 2016/10/11/us/weather-matthew-drone-rescue/index.html

Engelking, C. (April 7, 2018). *Drone Pilot Helps Rescue Flood Victims in Texas* Discover Magazine. https://blogs.discovermagazine.com/drone360/2015/05/21/drone-rescue-flood-victims/

Ferrandez, S. M., Harbison, T., Weber, T., Sturges, R., & Rich, R. (2016). Optimization of a truck-drone in tandem delivery network using k-means and genetic algorithm. *Journal of Industrial Engineering and Management (JIEM), 9*(2), 374-388.

Ferris-Rotman, A. (March 28, 2018). *How Drones Are Helping Nepal Recover From The Earthquake*. Huffington Post. https://www.huffingtonpost.com/2015/05/07/nepal-earthquake-drones n 7232764.html

Freedman, L. D. (2016). The drone revolution: Less than meets the eye. *Foreign Aff., 95*, 153.

Greenwood, W. (2018). UAV-Enabled Surface and Subsurface Characterization for Post-Earthquake Geotechnical Reconnaissance.

Ham, A. M. (2018). Integrated scheduling of m-truck, m-drone, and m-depot constrained by time-window, drop-pickup, and m-visit using constraint programming. *Transportation Research Part C: Emerging Technologies, 91*, 1-14.

Hatfield, R. A. (2017). *How much does a man cost? A dirty, dull, and dangerous application.*

Jenkins, D. & Vasigh, B. (2013). *The Economic Impact of Unmanned Aircraft Systems in the United States.* Association for Unmanned Vehicle Systems International.

Ji, G., & Zhu, C. (2012). A study on emergency supply chain and risk based on urgent relief service in disasters. *Systems Engineering Procedia, 5*, 313-325.

Keane, J. F., & Carr, S. S. (2013). A brief history of early unmanned aircraft. *Johns Hopkins APL Technical Digest, 32*(3), 558-571.

Khayal, D., Pradhananga, R., Pokharer, S., & Mutlu, F. (2015). A model for planning locations of temporary distribution facilities for emergency response. *Socio-economic planning sciences, 52*, 22-30. doi:10.1016/j.seps.2015.09.002

Kuo, L. (March 8, 2018). *Africa is now the worlds testing ground for commercial drones.* Quartz. https: //qz.com/1003810/the-worlds-first-commercial-drone-delivery- operates-from-a-hill-in-rwanda/

Leary, K. (April 2, 2018.). *Matternet Is Expanding Drone Delivery to Hospitals in Switzerland.* Futurism. https://futurism.com/matternet-is-expanding-drone-delivery-to- hospitals-in-switzerland/

Lei, L., Lee, K., & Dong, H. (2016). A heuristic for emergency operations scheduling with lead times and tardiness penalties. *European Journal of Operational Research, 250*(3), 726-736. doi:10.1016/j.ejor.2015.10.005

Meola, A. (6 March 2018). *Drone market shows positive outlook with strong industry growth and trends.* Business Insider. http://www.businessinsider.com/drone-industry-analysis-market- trends-growth-forecasts-2017-7

Mohammadi, M., Jula, P., & Tavakkoh-Moghaddam, R. (2019). Reliable single-allocation hub location problem with disruptions. *Transportation Research Part E-Logistics and Transportation Review, 123*, 90-120. doi:10.1016/j.tre.2019.01.008

Rabta, B., Wankmüller, C., & Reiner, G. (2018). A drone fleet model for last-mile distribution in disaster relief operations. *International Journal of Disaster Risk Reduction, 28*, 107-112.

Shavarani, S. M., Golabi, M., & Izbirak, G. A capacitated biobjective location problem with uniformly distributed demands in the UAV-supported delivery operation. *International Transactions in Operational Research*. doi:10.1111/itor.12735

Smith, J. (May 15, 2018). *Afghan drone war - data show unmanned flights dominate air campaign*. https://www.reuters.com/article/us-global-markets/asian-shares- falter-as-u-s-readies-china-tariffs-euro-at-2-week-low-on-ecb-idUSKBN1JB03U

Tanner, V. (2018). Using Drones in Disaster Areas: Perspectives of Disaster Responders in North Carolina, Virginia and Maryland.

Walsh, D., & Schmitt, E. (2018). *U.S. Strikes Al Qaeda Target in Southern Libya, Expanding Shadow War There.* New York Times.

Wang, K., Yuan, B., Zhao, M., & Lu, Y. (2019). Cooperative route planning for the drone and truck in delivery services: A bi-objective optimisation approach. *Journal of the Operational Research Society*, 1-18.

Wang, Q., & Rong, L. (2007). *Agile knowledge supply chain for emergency decision-making support.* Paper presented at the International Conference on Computational Science.

Xavier, I. R., de Mello Bandeira, R. A., de Oliveira Silva, L., Bandeira, A. d. P. F., & Campos, V. B. G. (2019). Employing helicopters in the modelling of last mile distribution system in large-scale disasters. *Transportation research procedia, 37*, 306-313.

Yeong, S., King, L., & Dol, S. (2015). A review on marine search and rescue operations using unmanned aerial vehicles. *Int. J. Mech. Aerosp. Ind. Mech. Manuf. Eng, 9*(2), 396-399.

Yurek, E. E., & Ozmutlu, H. C. (2018). A decomposition-based iterative optimization algorithm for traveling salesman problem with drone. *Transportation Research Part C: Emerging Technologies, 91*, 249-262.

APPENDIX

Python codes and result

```
import math

w = 22 #float(input('Enter the UAV max speed(km/h): '))/10
v = 8 #float(input('Enter the truck max speed(km/h): '))/10
Ɛr = 5 #float(input('Enter the max endurance of UAV(h): '))
remdistance = Ɛr * w

pCons = (v) / math.sqrt((w**2)-(v**2))

totaldemanpoints = 6 #int(input('Enter the number of demand points: '))
print()

listDemand = [['-4/11,14.36',['5','16'],['5.5','10']],['-
5/16.5,14.54',['21.5','9'],['26','5'],['29','3.5']],['0,5',['39.5','1']]]
#[]
'''
nl = int(input('Enter the number of the lines: '))

for i in range(nl):
    y = input('PLease enter equation(a,b) of line' + str(i+1) + ': ')
    lstcurrentline = []
    lstcurrentline.append(y)
    n = int(input('> Enter the number of demand points for line' + str(i+1)
+ ': '))
    print(">> Please enter the demand coordinates")
    for j in range(n):
        x = input('>>> Enter x' + str(j + 1) + ',y' + str(j + 1) + '
Conrdinator: ')
        lstcurrentline.append([x.split(',')[0], x.split(',')[1]])

    listDemand.append(lstcurrentline)
    print()
'''
listOnRoadDemand = []

for t in listDemand:
    eq = t[0]
    a0 = 0
    b0 = 0
    a1 = 0
    b1 = 0

    if(eq.split(',')[0] != '0'):
        a0 = float(eq.split(',')[0].split('/')[0]) /
float(eq.split(',')[0].split('/')[1])
        b0 = float(eq.split(',')[1])
        a1 = (-1)/(a0)
    else:
        a0 = 0
        b0 = float(eq.split(',')[1])
        a1 = 0

    for i in t[1:]:
        x = float(i[0])
        y = float(i[1])

        if(a1 == 0):
            b1 = x
        else:
            b1 = y - a1 * x
```

```
        if(a0 == 0 and a1 == 0):
            newX = round(b1,3)
            newY = round(b0,3)
        else:
            newX = round((b1 - b0)/(a0 - a1),3)
            newY = round(a0 * newX + b0, 3)

        m = round(math.sqrt(((newY-y)**2)+((newX-x)**2)),3)
        p = round(pCons * m, 3)
        px = round(newX - math.sqrt(p/((a0**2)+1)),3)
        py = round(px * a0 + b0,3)
        qx = round(newX + math.sqrt(p/((a0**2)+1)),3)
        qy = round(qx * a0 + b0,3)

        listOnRoadDemand.append([[x,y],[newX, newY],m,p,[px,py],[qx,qy]])

for item in listOnRoadDemand:
    print(item)

print()
print()
#starting jurney
for itemI in listOnRoadDemand:
    idxI = listOnRoadDemand.index(itemI)
    dx = itemI[0][0]
    dy = itemI[0][1]
    px = itemI[4][0]
    py = itemI[4][1]
    qx = itemI[5][0]
    qy = itemI[5][1]

    m = itemI[2]
    p = itemI[3]
    distance = round(math.sqrt((dy-py)**2+(dx-px)**2),3)
    #print('P'+str(idxI+1)+':',distance,'\tQ'+str(idxI+1)+':',distance)
    if(idxI+2<len(listOnRoadDemand)):
        for itemJ in listOnRoadDemand[idxI+1:idxI+2]:
            idxJ = listOnRoadDemand.index(itemJ)
            dx1 = itemJ[0][0]
            dy1 = itemJ[0][1]
            px1 = itemJ[4][0]
            py1 = itemJ[4][1]
            qx1 = itemJ[5][0]
            qy1 = itemJ[5][1]

            m1 = itemJ[2]
            p1 = itemJ[3]
            distance01 = round(math.sqrt((py-py1)**2+(px-px1)**2),3)
            distance1 = round(math.sqrt((dy1-py1)**2+(dx1-px1)**2),3)
            for itemK in listOnRoadDemand[idxI + 2:idxI + 3]:
                idxK = listOnRoadDemand.index(itemK)
                dx2 = itemK[0][0]
                dy2 = itemK[0][1]
                px2 = itemK[4][0]
                py2 = itemK[4][1]
                qx2 = itemK[5][0]
                qy2 = itemK[5][1]

                m2 = itemK[2]
                p2 = itemK[3]
                distance12 = round(math.sqrt((py1 - py2) ** 2 + (px1 - px2)
** 2), 3)
                distance2 = round(math.sqrt((dy2 - py2) ** 2 + (dx2 - px2)
** 2), 3)

        print('Individually Launch',str(idxI + 1))
```

```
        print('Launch '+ str(idxI + 1)+':',distance,', Retrieve '+ str(idxI
+ 1),':',distance)
        print('>>> Sum :',round(distance + distance,3))
        print()
        print('Combination Launch',str(idxI + 1),'and',str(idxJ + 1))
        print('Launch ' + str(idxI + 1) + ':', distance, '\tLaunch
'+str(idxI + 1)+' to ' + str(idxJ + 1) + ':',
              distance01, '\tRetrieve ' + str(idxJ + 1) + ':',distance1)
        print('>>> Sum :', round(distance + distance01 + distance1,3))
        print()
        print('Combination Launch',str(idxI + 1),',',str(idxJ +
1),'and',str(idxK + 1))
        print('Launch ' + str(idxI + 1) + ':', distance, '\tLaunch
'+str(idxI + 1)+' to ' + str(idxJ + 1) + ':',
              distance01, '\tLaunch '+str(idxJ + 1)+' to ' + str(idxK + 1)
+ ':',
              distance12,'\tRetrieve ' + str(idxK + 1) + ':',distance2)
        print('>>> Sum :', round(distance + distance01 +
distance12+distance2,3))
        print('==================')
    elif(idxI+2 == len(listOnRoadDemand)):
        for itemJ in listOnRoadDemand[idxI + 1:idxI + 2]:
            idxJ = listOnRoadDemand.index(itemJ)
            dx1 = itemJ[0][0]
            dy1 = itemJ[0][1]
            px1 = itemJ[4][0]
            py1 = itemJ[4][1]
            qx1 = itemJ[5][0]
            qy1 = itemJ[5][1]

            m1 = itemJ[2]
            p1 = itemJ[3]
            distance01 = round(math.sqrt((py - py1) ** 2 + (px - px1) **
2), 3)
            distance1 = round(math.sqrt((dy1 - py1) ** 2 + (dx1 - px1) **
2), 3)
        print('Individually Launch', str(idxI + 1))
        print('Launch ' + str(idxI + 1) + ':', distance, ', Retrieve ' +
str(idxI + 1), ':', distance)
        print('>>> Sum :', round(distance + distance, 3))
        print()
        print('Combination Launch', str(idxI + 1), 'and', str(idxJ + 1))
        print('Launch ' + str(idxI + 1) + ':', distance, '\tLaunch ' +
str(idxI + 1) + ' to ' + str(idxJ + 1) + ':',
              distance01, '\tRetrieve ' + str(idxJ + 1) + ':', distance1)
        print('>>> Sum :', round(distance + distance01 + distance1, 3))
        print('==================')
    else:
        print('Individually Launch', str(idxI + 1))
        print('Launch ' + str(idxI + 1) + ':', distance, ', Retrieve ' +
str(idxI + 1), ':', distance)
        print('==================')
```

```
/Users/appleonline/PycharmProjects/untitled/thesisapp/venv/bin/python /Users/appleonline/PycharmProjects/untitled/thesisapp/thesispy.app.py

[[5.0, 16.0], [3.889, 12.946], 3.25, 1.269, [2.83, 13.331], [4.948, 12.561]]
[[5.5, 10.0], [6.258, 12.084], 2.218, 0.866, [5.383, 12.403], [7.133, 11.766]]
[[21.5, 9.0], [21.229, 8.107], 0.933, 0.364, [20.652, 8.282], [21.806, 7.932]]
[[26.0, 5.0], [26.461, 6.522], 1.59, 0.621, [25.707, 6.75], [27.215, 6.293]]
[[29.0, 3.5], [29.625, 5.563], 2.156, 0.842, [28.747, 5.829], [30.503, 5.297]]
[[39.5, 1.0], [39.5, 5.0], 4.0, 1.561, [38.251, 5.0], [40.749, 5.0]]


Individually Launch 1
Launch 1: 3.44 , Retrieve 1 : 3.44
>>> Sum : 6.88

Combination Launch 1 and 2
Launch 1: 3.44  Launch 1 to 2: 2.716    Retrieve 2: 2.406
>>> Sum : 8.562

Combination Launch 1 , 2 and 3
Launch 1: 3.44  Launch 1 to 2: 2.716    Launch 2 to 3: 15.815     Retrieve 3: 1.111
>>> Sum : 23.082
==================
Individually Launch 2
Launch 2: 2.406 , Retrieve 2 : 2.406
>>> Sum : 4.812

Combination Launch 2 and 3
Launch 2: 2.406     Launch 2 to 3: 15.815   Retrieve 3: 1.111
>>> Sum : 19.332

Combination Launch 2 , 3 and 4
Launch 2: 2.406     Launch 2 to 3: 15.815   Launch 3 to 4: 5.282   Retrieve 4: 1.774
>>> Sum : 25.277
==================
Individually Launch 3
Launch 3: 1.111 , Retrieve 3 : 1.111
>>> Sum : 2.222

Combination Launch 3 and 4
```

```
Launch 3: 1.111     Launch 3 to 4: 5.282    Retrieve 4: 1.774
>>> Sum : 8.167

Combination Launch 3 , 4 and 5
Launch 3: 1.111     Launch 3 to 4: 5.282    Launch 4 to 5: 3.176   Retrieve 5: 2.343
>>> Sum : 11.912
==================
Individually Launch 4
Launch 4: 1.774 , Retrieve 4 : 1.774
>>> Sum : 3.548

Combination Launch 4 and 5
Launch 4: 1.774     Launch 4 to 5: 3.176    Retrieve 5: 2.343
>>> Sum : 7.293

Combination Launch 4 , 5 and 6
Launch 4: 1.774     Launch 4 to 5: 3.176    Launch 5 to 6: 9.54    Retrieve 6: 4.19
>>> Sum : 18.68
==================
Individually Launch 5
Launch 5: 2.343 , Retrieve 5 : 2.343
>>> Sum : 4.686

Combination Launch 5 and 6
Launch 5: 2.343     Launch 5 to 6: 9.54     Retrieve 6: 4.19
>>> Sum : 16.073
==================
Individually Launch 6
Launch 6: 4.19 , Retrieve 6 : 4.19
==================

Process finished with exit code 0
```