Optimizing Middle Mile Logistics: Vertiport Placement in Gyeongsangbuk-do and Daegu through K-Means Algorithm

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Contents

Meet the Team

Meet the Team

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Role: Algorithm Development and Optimization

Team member

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Role: Research Hypothesis Development and Validation

Team member

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Major: Communication Art/ Data Science
Role: Storytelling and Data Science Integration

Team member

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Major: Life Science/AI Convergence
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Team member

Name: Juchan Lee
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Major: ICT Convergence/Data Science
Role: Data Collection and Hypothesis Validation

Advisors

Academic Advisor

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Handong Global University

Handong Global University	(Mar. 2022 – Present)
American Airlines	(May 2021 – Feb. 2022)
Hyundai Motor Company	(Dec. 2020 – Jan. 2021)
Samsung Electronics	(May 2020 – Aug. 2020)
CJ Logistics	(May 2018 – Aug. 2018)
Siemens (CD-adapco)	(May 2016 – Aug. 2016)
Aerospace Systems Design Laboratory	(Jan. 2016 – Aug. 2019)
Korea Aerospace Research Institute	(Jan. 2014 – Jul. 2015)
University of Alberta	(Dec. 2012 – Feb. 2013)

Technical Advisor

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Senior Manager, Advanced Air Mobility (AAM) Business Planning & Execution Team,
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Hyundai Motor Company	(Feb. 2022 - Present)
Asiana Airlines	(Mar. 2018 - Feb. 2022)
Eastar Jet	(Apr. 2017 - Jan. 2018)
KEIT	(Oct. 2012 - July 2014)
Hanwha Corporation	(Jul. 2010 - Oct. 2012)
Republic of Korea Army	(Mar. 2006 - June 2008)

Introduction

Introduction

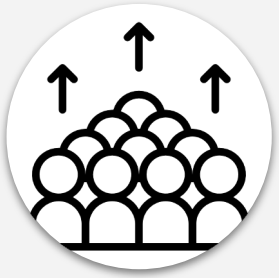
- What is AAM?
  - Advanced Air Mobility (AAM):
    A new paradigm in aviation that involves the use of advanced technologies to enable safe, efficient, and sustainable air transportation

https://www.youtube.com/watch?v=Z65Xmnuq7JM

Introduction

- Emergence of AAM

Population Increase



Urbanization

Traffic Congestion

https://www.joongang.co.kr/article/24105798

CO2 Emission

https://youmatter.world/en/greenhouse-gases-co2-decarbonizing-28439/

Necessity for a New Paradigm in Transportation

Introduction

- What about using Helicopter?

https://eibery77.tistory.com/390

Helicopter **maintenance costs 152.6 billion won** over the past five years

https://m.kmib.co.kr/view.asp?arcid=0924101349

Helicopter **noise pollution** in certain areas has disrupted the livelihood of residents

http://www.wj1news.com/news/article.html?no=4867

Introduction

- Types of AAM
  - AAM can be separated into two groups:
    1) **Urban Air Mobility (UAM)**
    2) **Regional Air Mobility (RAM)**

Urban Air Mobility (UAM)		Regional Air Mobility (RAM)
Air transportation system moves **within** the urban/suburban areas at lower altitudes	**Definition**	Air transportation system moves **between** regional centers
transportation of people and goods **in the city**	**feature**	People & freight transport between **regional bases**
100 km+	**Distance/Range**	**200 km+**

https://blog.hyundai-transys.com/302

Introduction

- Types of AAM Craft

[1]

[2]

[3]

Type	Vector Thrust	Lift + Cruise	Multicopter
Concept	Tilting the Rotors to Topside/Front	Fixed Wing & Rotors	Multiple Rotors
Technical Level	Highest	Intermediate	Relatively Low
Payload	5 Seats or More	4 or 5 Seats	1 or 2 Seats

[1] https://evtol.news/joby-s4
[2] https://evtol.news/kitty-hawk-cora
[3] https://evtol.news/volocopter-volocity/

Introduction

- Applications of AAM

ROTORCRAFT

Electric Air Taxis Take Flight in New York City

Joby and Volocopter fly their eVTOL prototypes from the Downtown Manhattan Heliport

Tourists Will Soon Enjoy Emission-Free eVTOL Flights Over the Great Barrier Reef

Published: 6 Dec 2021, 07:47 UTC • By: Otilia Drăgan

Ecotourism is on a path to redefining itself by also including environmentally friendly means of transportation, from hybrid-electric ground vehicles and ferries to electric vertical take-off and landing (eVTOL) aircraft.

Pipistrel Announces Hybrid Electric Cargo eVTOL

By Paul Bertorelli - Published: September 1, 2020

Passenger Transportation

Leisure & Tour

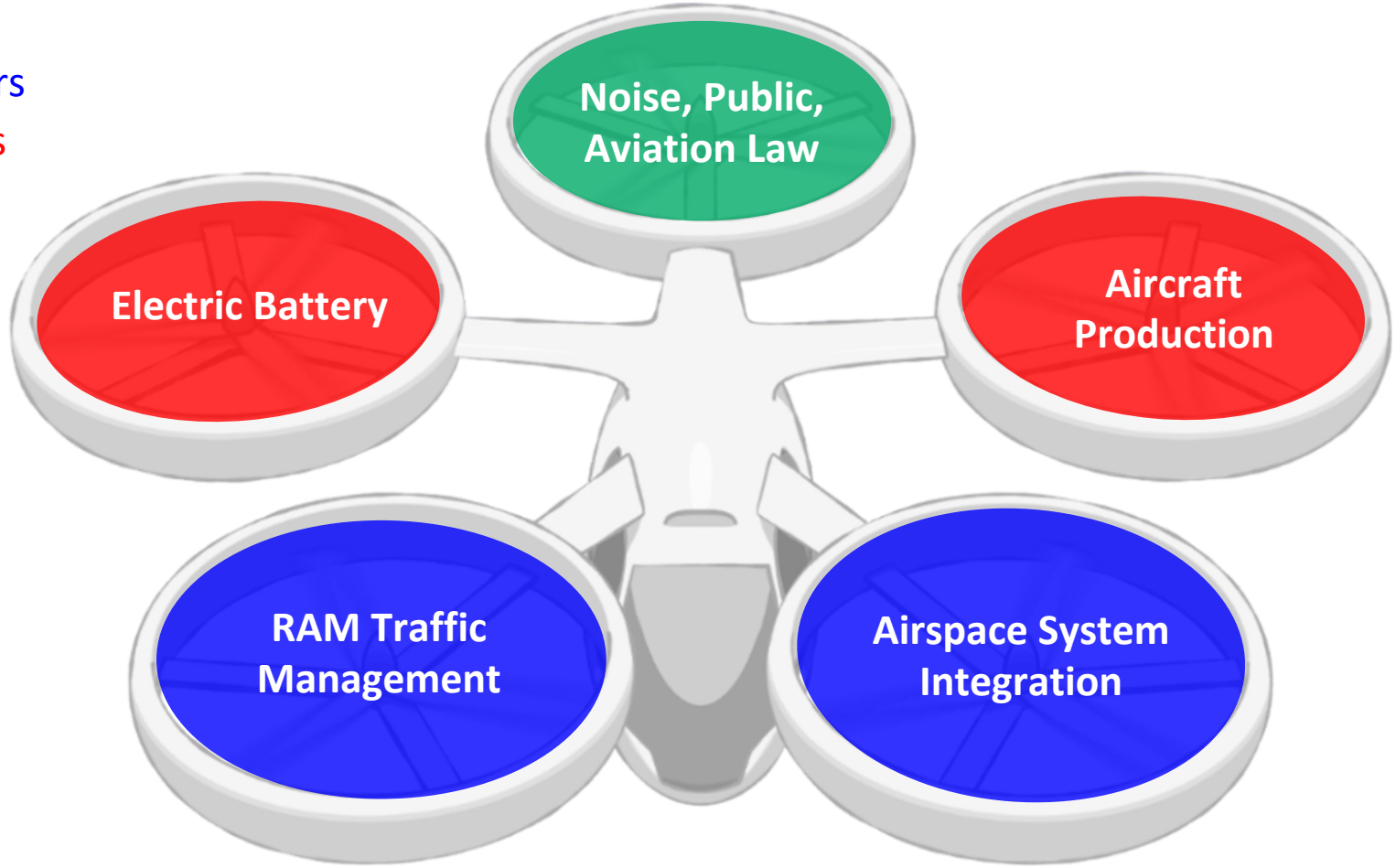
Cargo Transportation

https://newatlas.com/aircraft/skydrive-evtol-2023-revised-design-specs/
https://www.autoevolution.com/news/tourists-will-soon-enjoy-emission-free-evtol-flights-over-the-great-barrier-reef-175776.html
https://www.avweb.com/aviation-news/pipistrel-announces-hybrid-electric-cargo-evtol/

Introduction

- Challenges of AAM

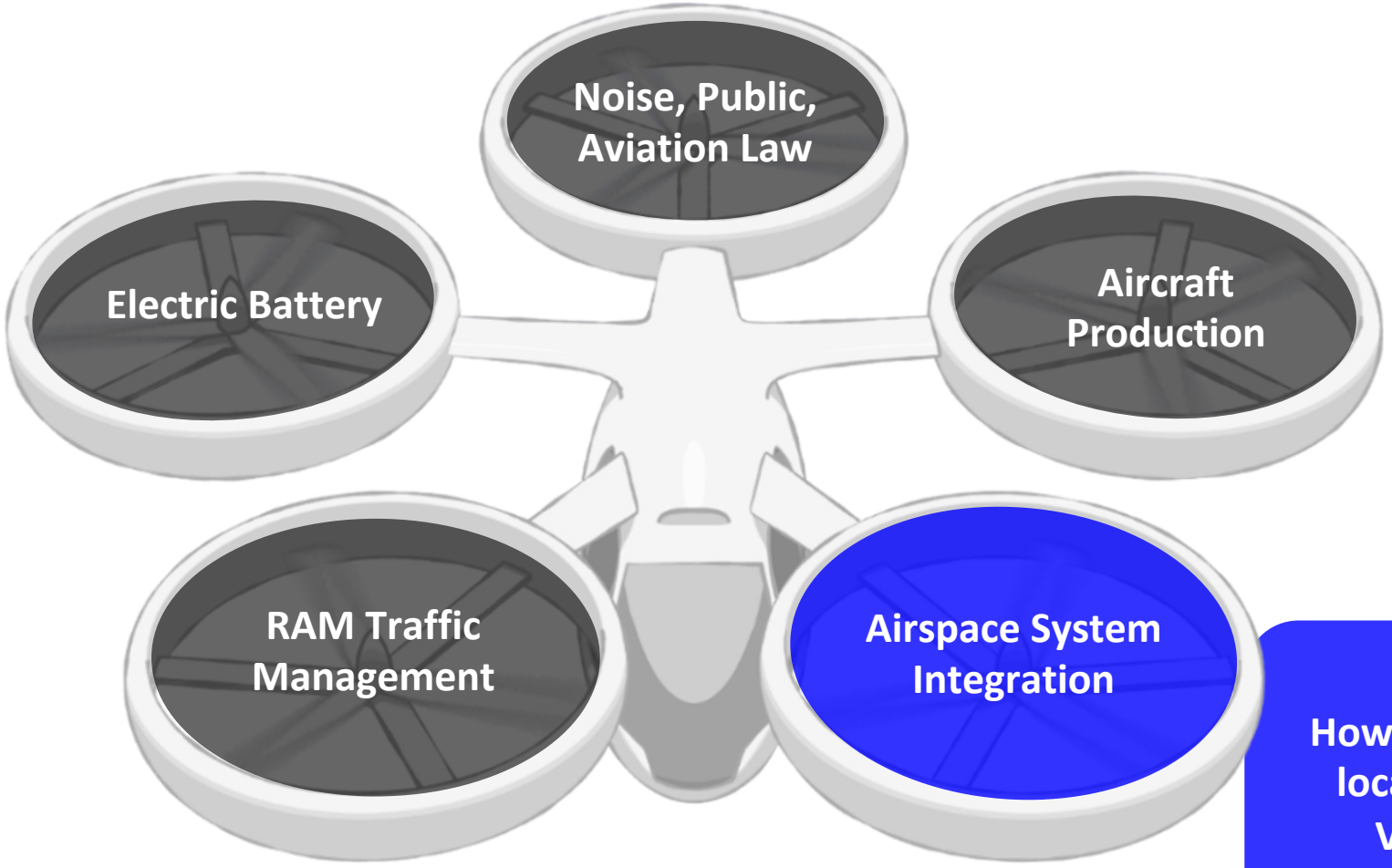
Airspace Barriers
Aircraft Barriers
Policy Barriers



Reproduce with modification from Chancey E. T(2020) and Kim & Kim(2023)

Introduction

- Challenges of AAM



How to select the location of the Vertiport?

Reproduce with modification from Chancey E. T(2020) and Kim & Kim(2023)

Research Motivation

Research Motivation

- Previous studies related to vertiport placement

Author (year)	Research Purpose	Considered Variables
Moon et al (2021)	Identifying the Potential Vertiport Location for Addressing Traffic in the Busan Area	Transportation connectivity, **Workplace density**, Official land price, **Number of commuters, Estimated income quintil**e, **Average transportation cost, Parking lot accessibility, Residential density, Noise**,
Sung et al (2023)	Optimal Location Selection and Efficiency Analysis of Driving Route Travel Time for Practical Use of Vertiport	Airspace restriction area, Natural environment conservation area, river, **Public transportation demand, Living population density, Average annual income,** Individual official land price, Transportation connection, **Residential density**
Jeong and Hwang (2021)	Analysis of demand for eVTOL to reduce commuting time in the Seoul metropolitan area and selection of vertiport location	**Commuting population**, Green belt, Airspace restriction area, **Residential area**
Kim et al (2023)	Suggesting the direction of vertiport construction to increase usage through analysis in terms of usage environment	Accessibility, Affordability, **Living environment**
Jung et al (2021)	Deriving Vertiport Location Selection Factors and Analysis of Location Assessment Factors	Land costs, Transportation connectivity, Obstacles, Ease of supply and construction of power sources, **Noise environment**, Law
Son et al (2023)	Selecting the location of the vertiport in the Seoul metropolitan area, building a network, estimating usage, and calculating the scale of the vertiport	**Traffic volume**
Min et al (2020)	Select a vertiport construction area in Seoul by analyzing the composition of physical infrastructure and considerations by type	Airspace restriction area in Seoul, **Floating population**, Connection of ground transportation

Focused on 1) Passenger Transportation in the 2) Mega city such as Seoul

Research Motivation

- Why did we focus on Logistic?

3 대중수용성 확대를 위한 단계적 서비스 실현

(1) 화물→사람으로 단계적 확대

□ **필요성**

○ **UAM**은 여객수송과 **화물운송**을 함께 실현시킬 수 있는 **종합교통 운송체계**로 역할 가능

○ eVTOL(600kg↑) 상용화('25) 전 **화물용 초경량급 드론**(150kg↓)을 활용해 우선 **상용서비스**가 가능한 **유망서비스**로 접근 가능

- **화물운송용** 비행체는 여객운송용과 **안전도 요구수준**이 상이해 **기술개발·인증**을 비교적 **빠르게 진행** 가능

○ UAM 대상 비행체의 **지속적인 운항데이터 확보**는 기술적 속도와 대중적 수용성 확보뿐만 아니라 **한국형UTM** 개발을 위해서도 중요

Korean Urban Air Mobility (K-UAM) Roadmap that opens the sky of the city (2020)

Logistics Transportation has higher feasibility compared to passenger transportation

Research Motivation

- Why did we target Daegu & Gyeongsangbuk-do?

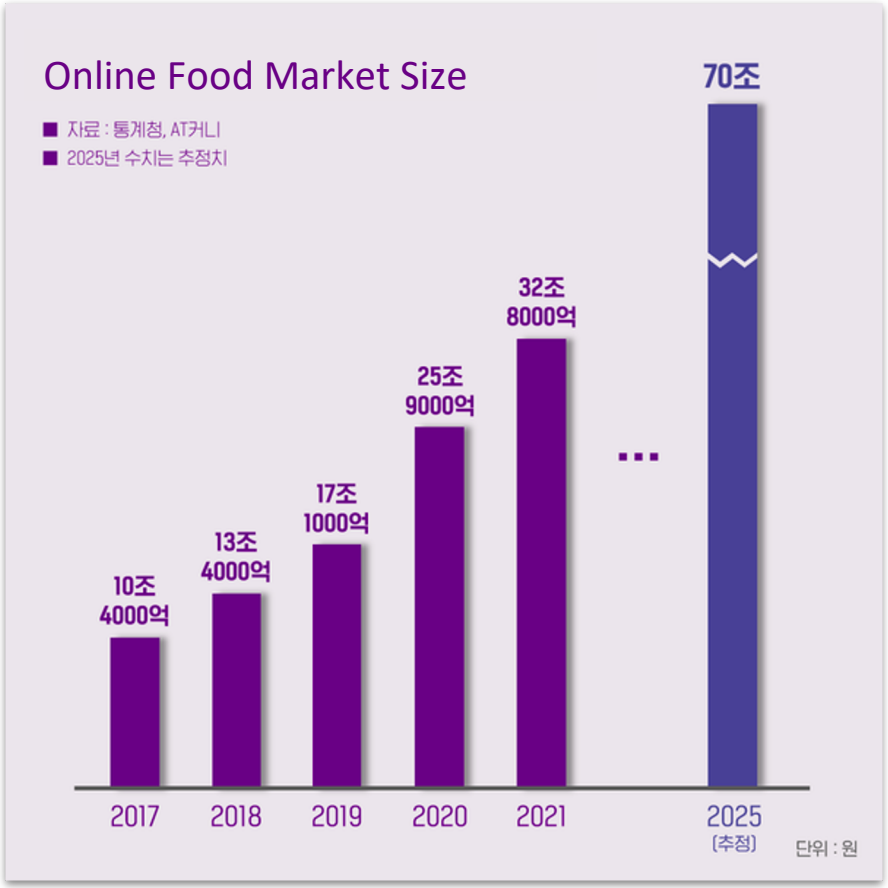
https://m.khan.co.kr/politics/defense-diplomacy/article/202008281651001#c2b

https://www.imaeil.com/page/view/2023110716343247708

Facilitate logistics transportation in Daegu & Gyeongsangbuk-do after relocation of Daegu airport (TK airport)

Research Motivation

- Continuous Growth of Fresh Food Delivery Market



https://www.klnews.co.kr/news/articleView.html?idxno=304588

Fresh Food Delivery Market is growing continuously as E-commerce market growing

Research Motivation

- Problems in Fresh food delivery system

Traffic Congestion

Daegu and Gyeongsangbuk-do had about **6.46 billion won** of traffic congestion cost in 2018.

(KOTI(한국 교통 연구원), 2018)

Delivery Vehicle Idling and Freshness Deterioration

Drivers occasionally turn off the engine of refrigerated trucks to save fuel during middle mile delivery

⇒ **Inadequate temperature control & spoilage of fresh food**

(대한경제, 2020)

Extended Delivery Times

Intensive consumer complaints regarding **'delay' and 'service'** in parcel delivery in 2022 (70%)

(소비자가 만드는 신문,2023)

Challenges of Delivering in Mountainous Regions

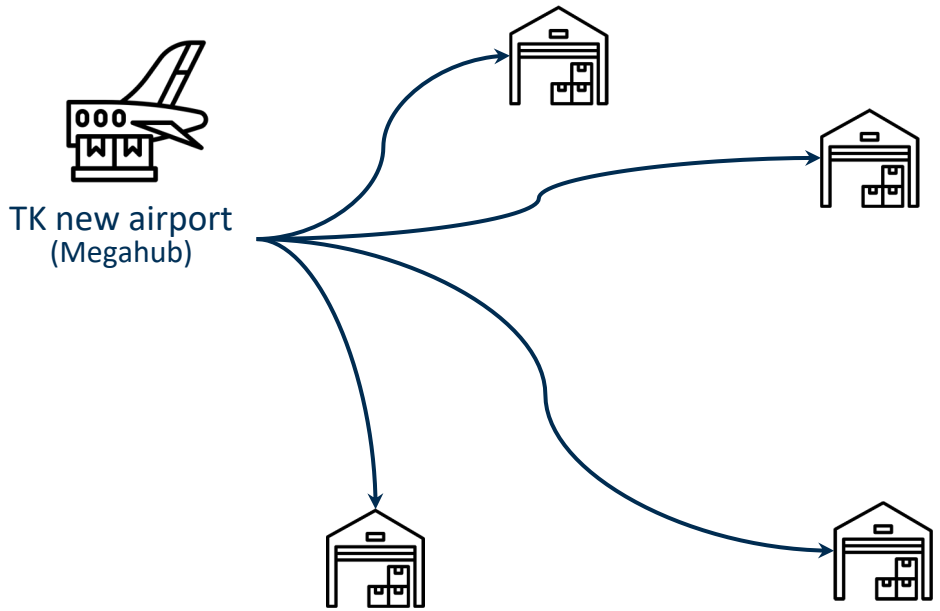
Fuel efficiency reduces by approximately 5.4% when the vehicles cruise on the slope

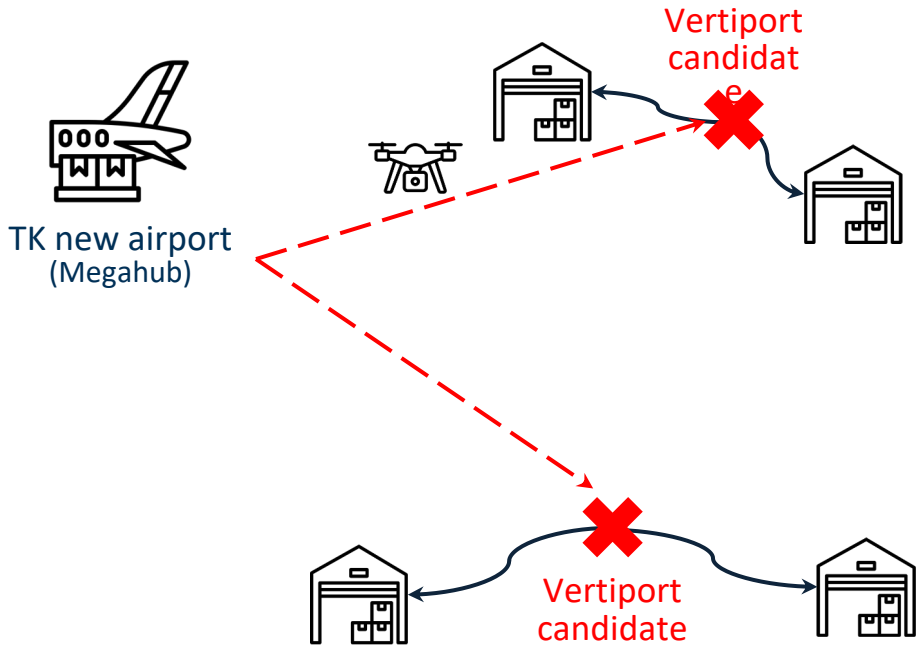
(Choi & Oh, 2011)

Research Motivation

Research Goal

- Identify optimal Vertiport candidates in Daegu and Gyeongsangbuk-do, to improve the middle mile delivery of fresh food.





Fresh Food spends long time on the road

Fast & Efficient delivery of fresh food by eVTOL

Research Motivation

- Comparison of Past Research Studies (Considered Variables)

Other studies

Commuters #
(Demand)

Estimated income quintile (Demand)

Residential Area

Public Transportation Connectivity
(Subway, Bus Stop)

Airspace restriction

Traffic Volume

=> Passenger transportation

Our study

Cargo Volume of warehouse
(Demand)

Airspace restriction area

Terrain slope
(According to EASA vertiport guideline)

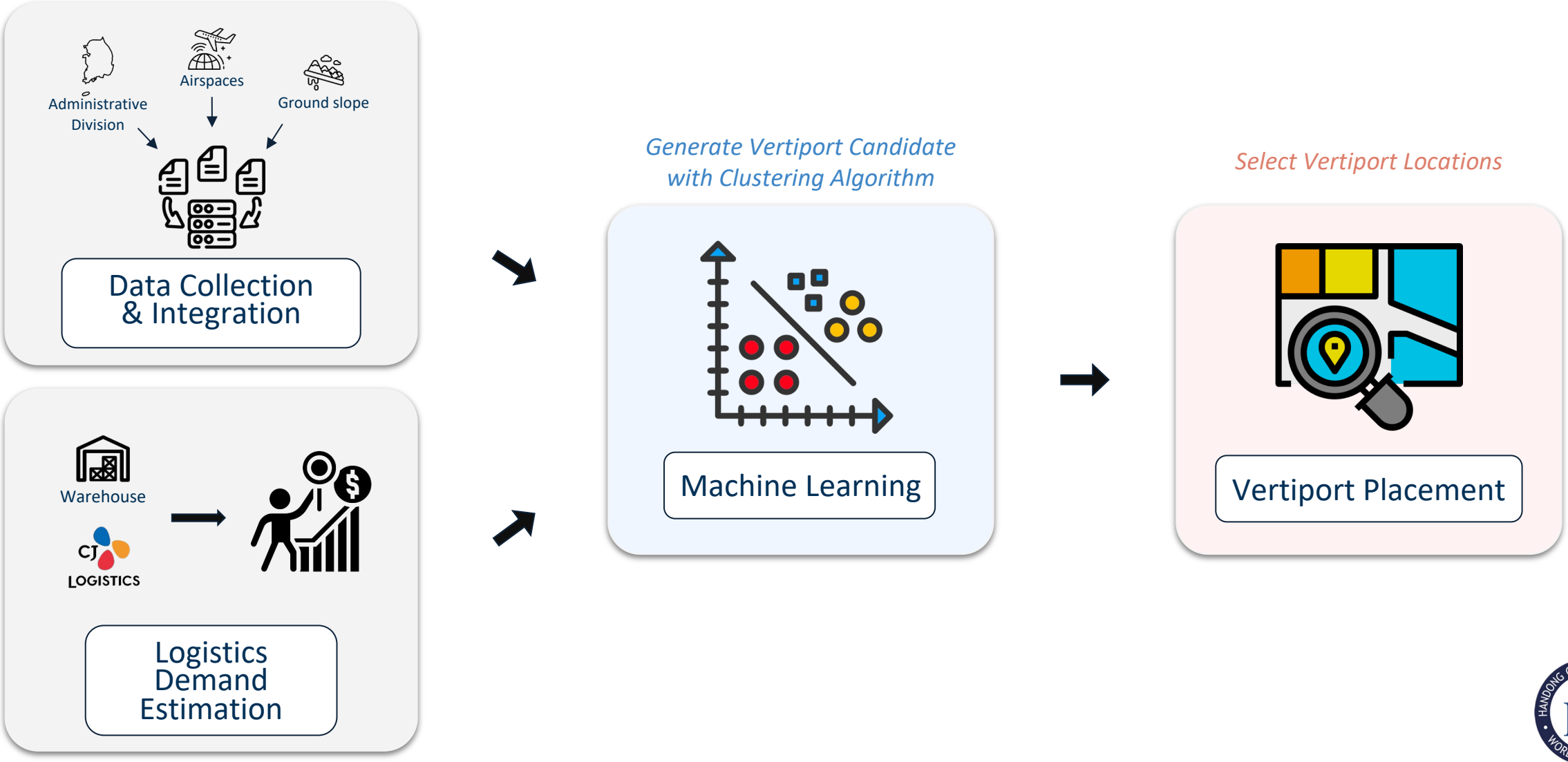
Ground Traffic connectivity
(Road)

=> Cargo transportation

Proposed Methodology

Proposed Methodology

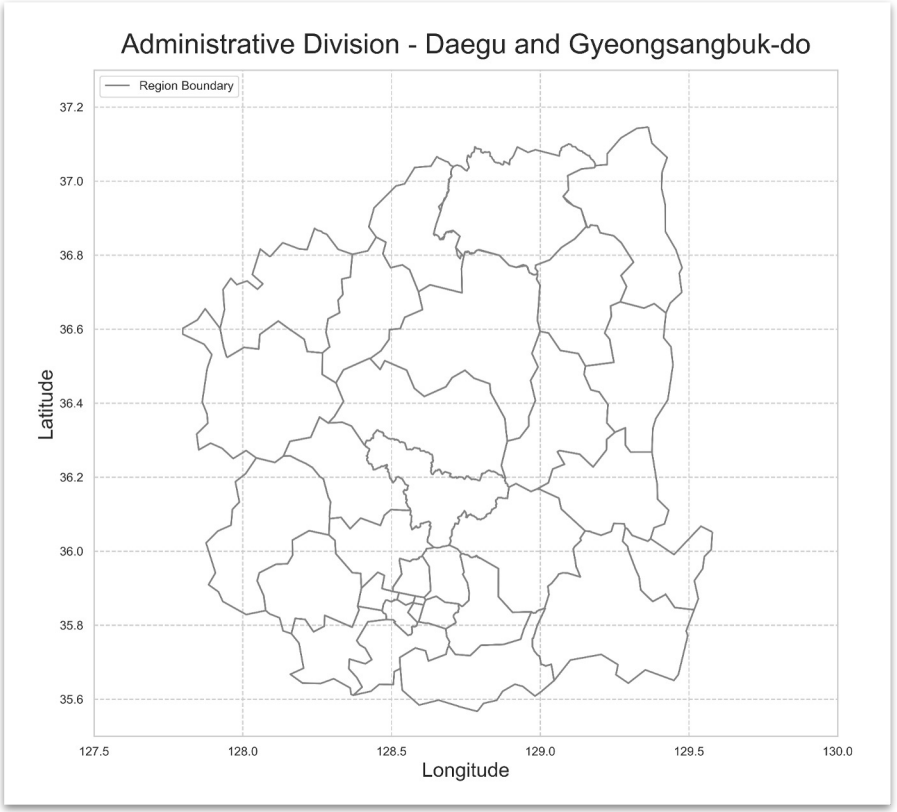
- Overview about framework developed for this project



Proposed Methodology

- Data Collection
  1. Administrative Division Data

https://www.worldatlas.com/maps/south-korea

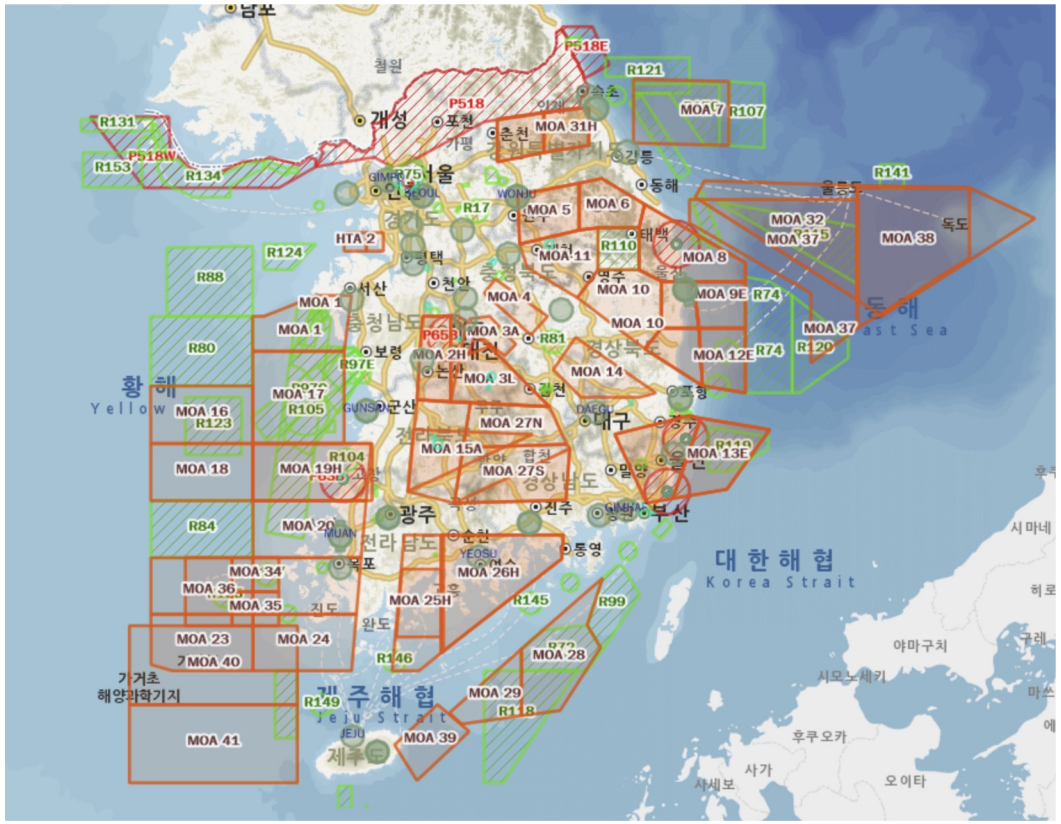


Employ the administrative division data to specify the research areas of this project: Daegu & Gyeongsangbuk-do

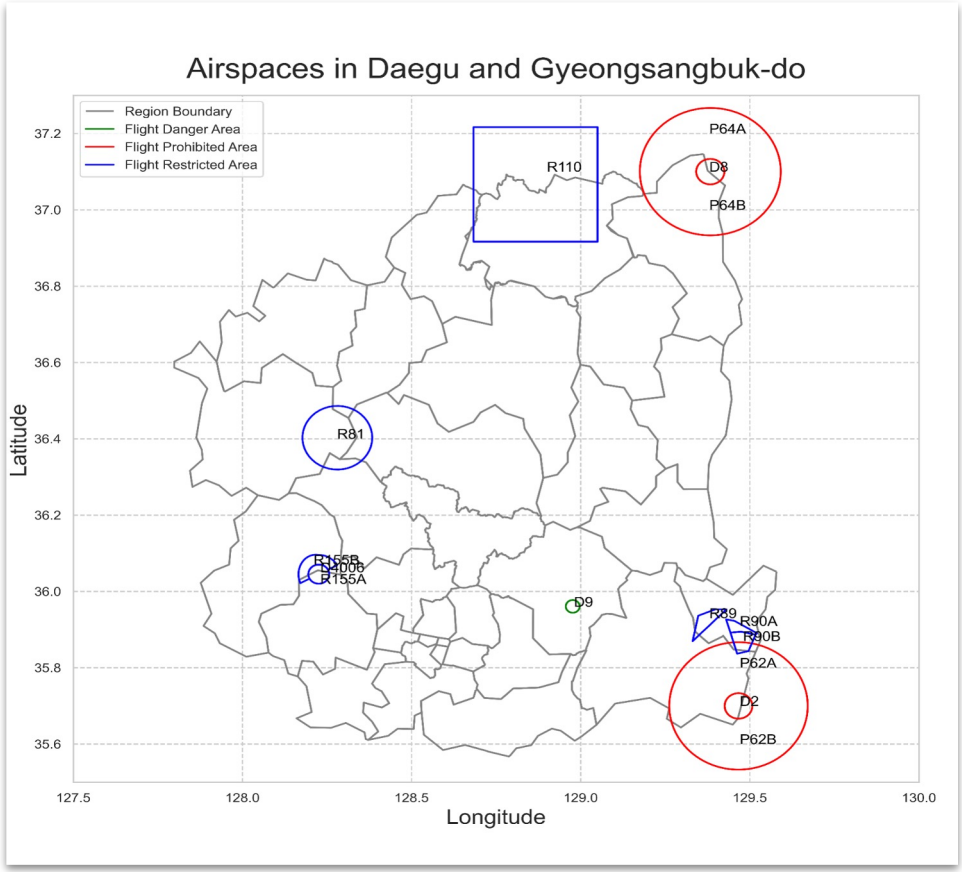
Proposed Methodology

- Data Collection

  2. Airspace Data (*Airspace: Space for aircraft activities with safety regulations to control air navigation)



https://map.vworld.kr/map/ws3dmap.do?initTab=layer&initMode=2D&lyrIde=LYRIDE_0000000000179



Collect & visualize the airspace data of South Korea to reflect the constraints on vertiport placement.

Proposed Methodology

- Data Collection

  3. Ground Slope Data (Guideline on the Vertiport Design from EASA (European Aviation Safety Agency)

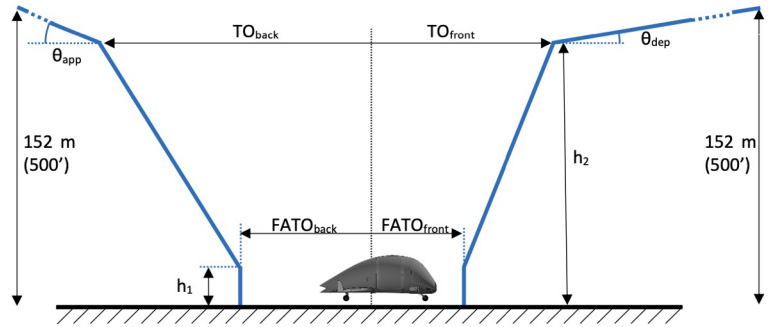


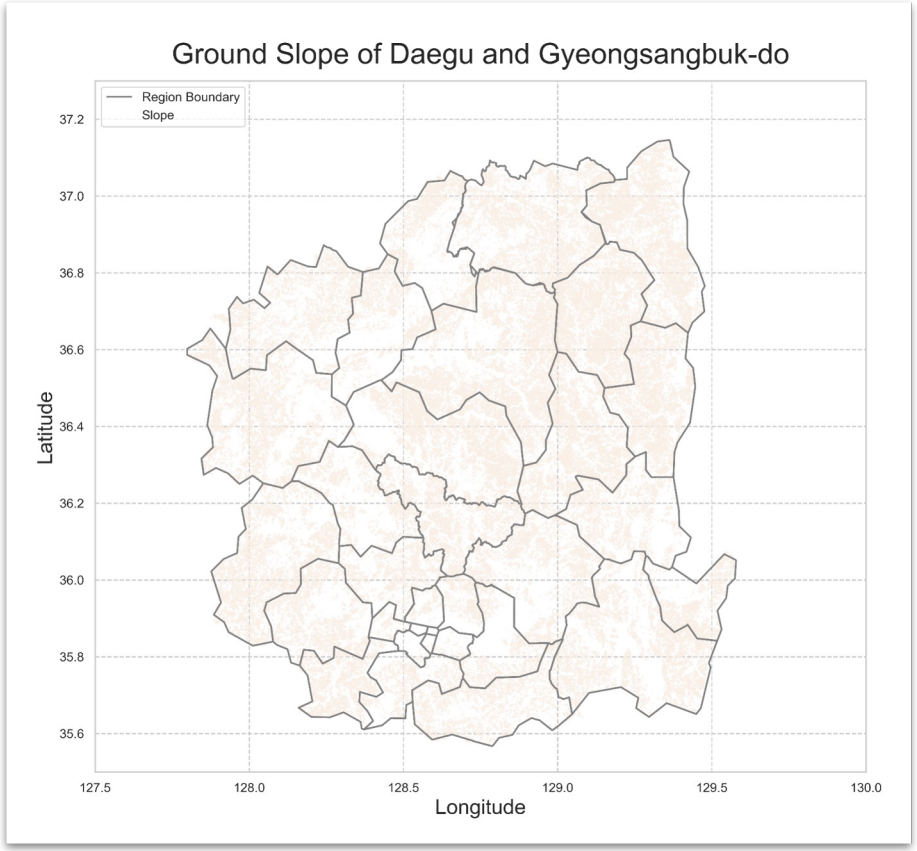
Figure D-13. Generic vertical take-off and landing procedure parameters

(3) To qualify as a vertical take-off and landing procedure, the parameters defining the procedure must meet certain minima or maxima as provided in Table D-3.

Parameter	Minimum/maximum
h_1	-
h_2	≥ h_1
TO_{width}	≤ 5 D
TO_{front}	≤ 5 D
TO_{back}	≤ 5 D
$FATO_{width}$	≥ 1.5 D
$FATO_{front}$	≥ 0.75 D
$FATO_{back}$	≥ 0.75 D
θ_{app}	≥ 4.5%
θ_{dep}	≥ 4.5%

Table D-3. Vertical take-off and landing procedure parameters minima/maxima

https://www.easa.europa.eu/en/prototype-technical-design-specifications-vertiports

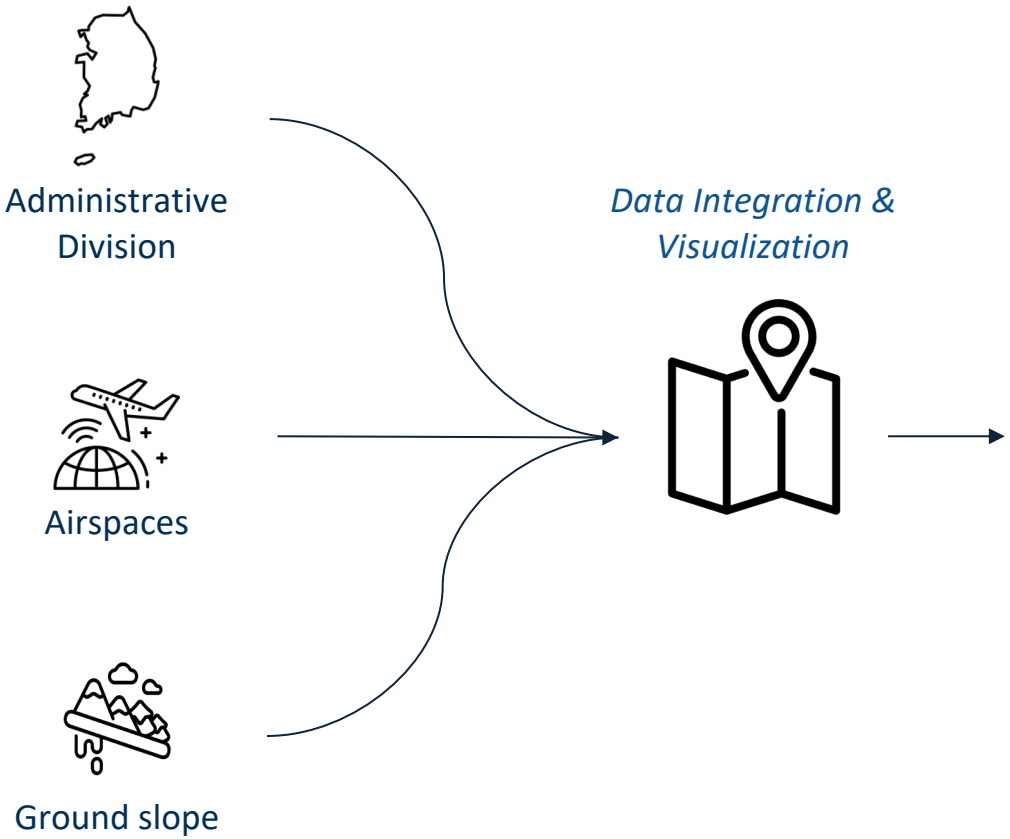


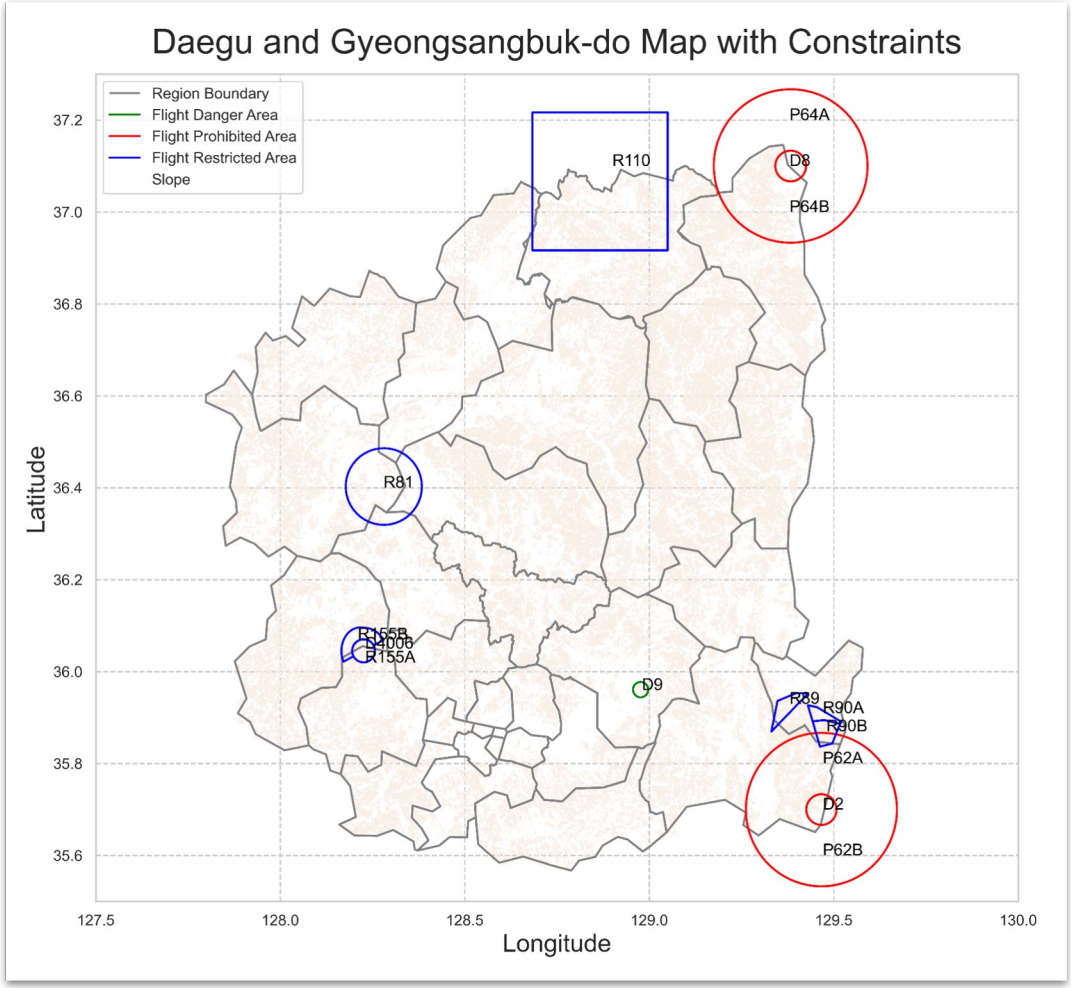
Collect & visualize areas where vertiport placement is constrained (i.e., slope > 0.5) on the map

Proposed Methodology

- Data Integration

  4. Integrate data to address constraints in our research topic





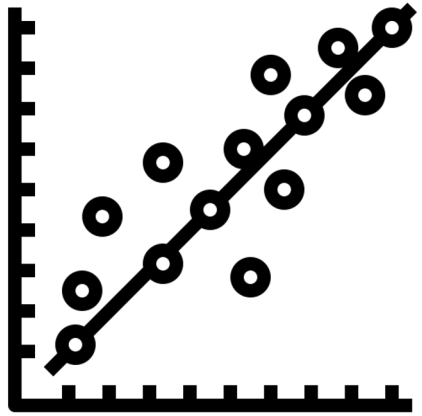
Proposed Methodology

- Logistics Demand Estimation
  - Estimate the relationship between warehouse volume and logistics demand with Hwaseong last mile data from CJ logistics

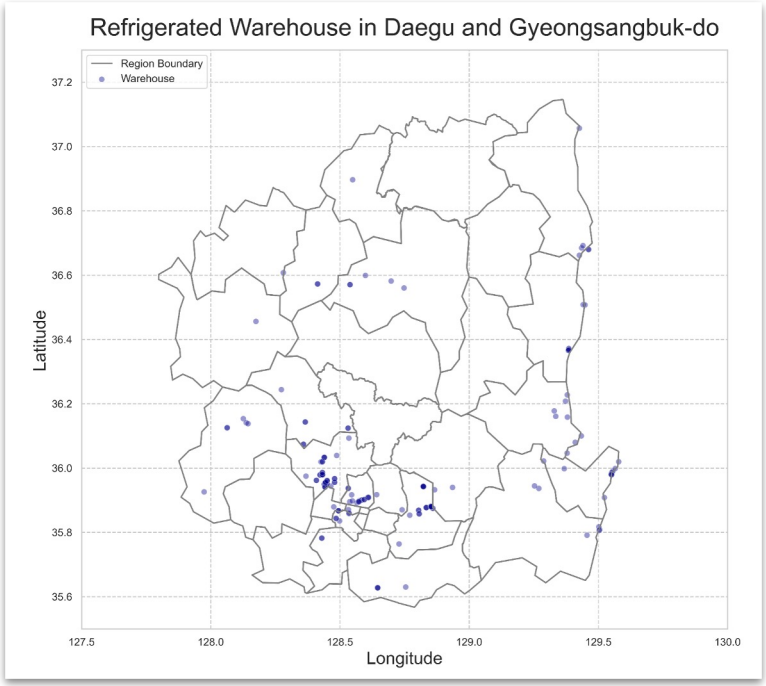
Warehouse

Last Mile

Derive the Linear Regression Equation



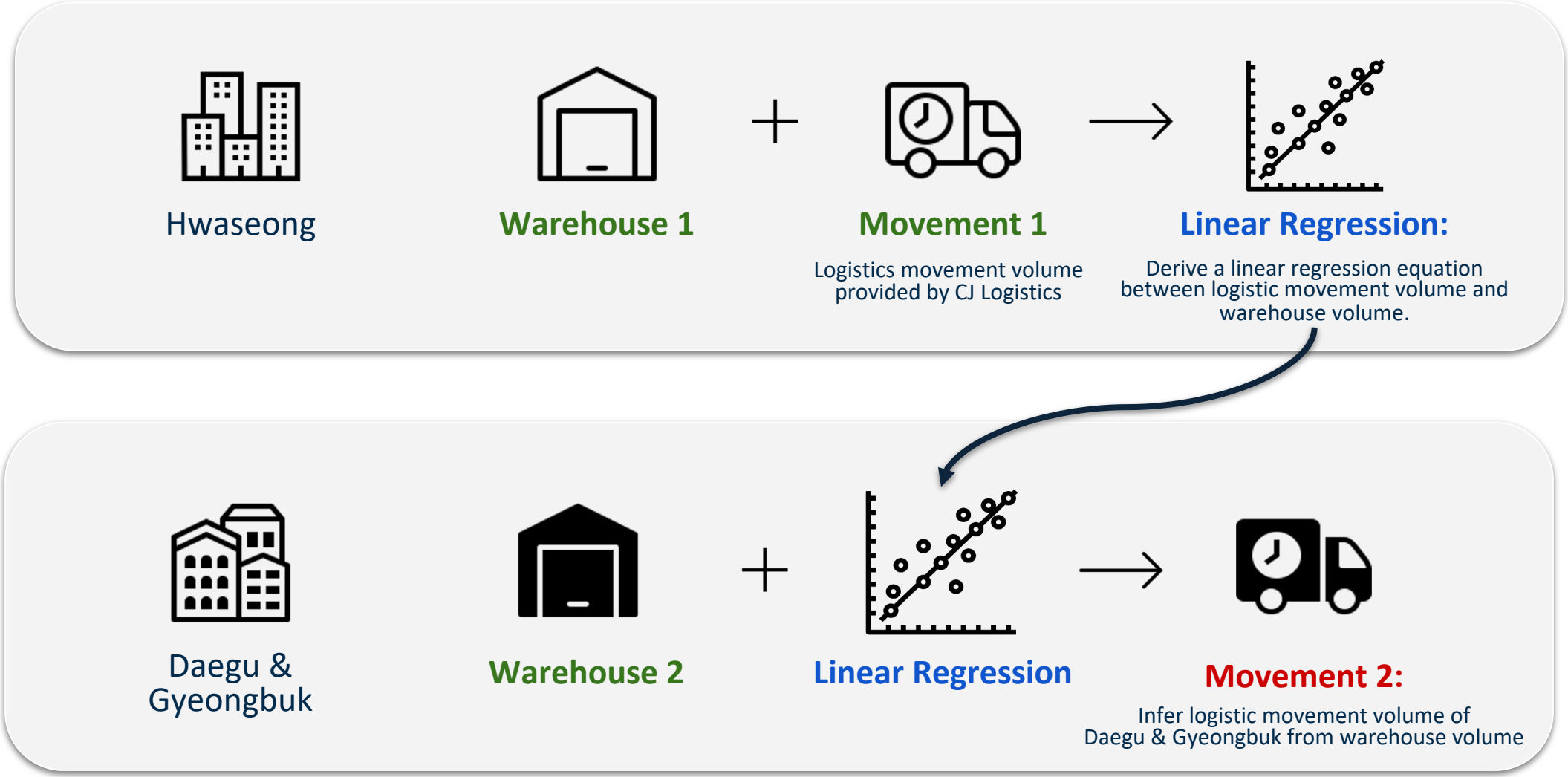
Apply to Daegu and Gyeongsangbuk-do Region



Hypothesis 1: "There is a positive correlation between warehouse volume and logistics demand."

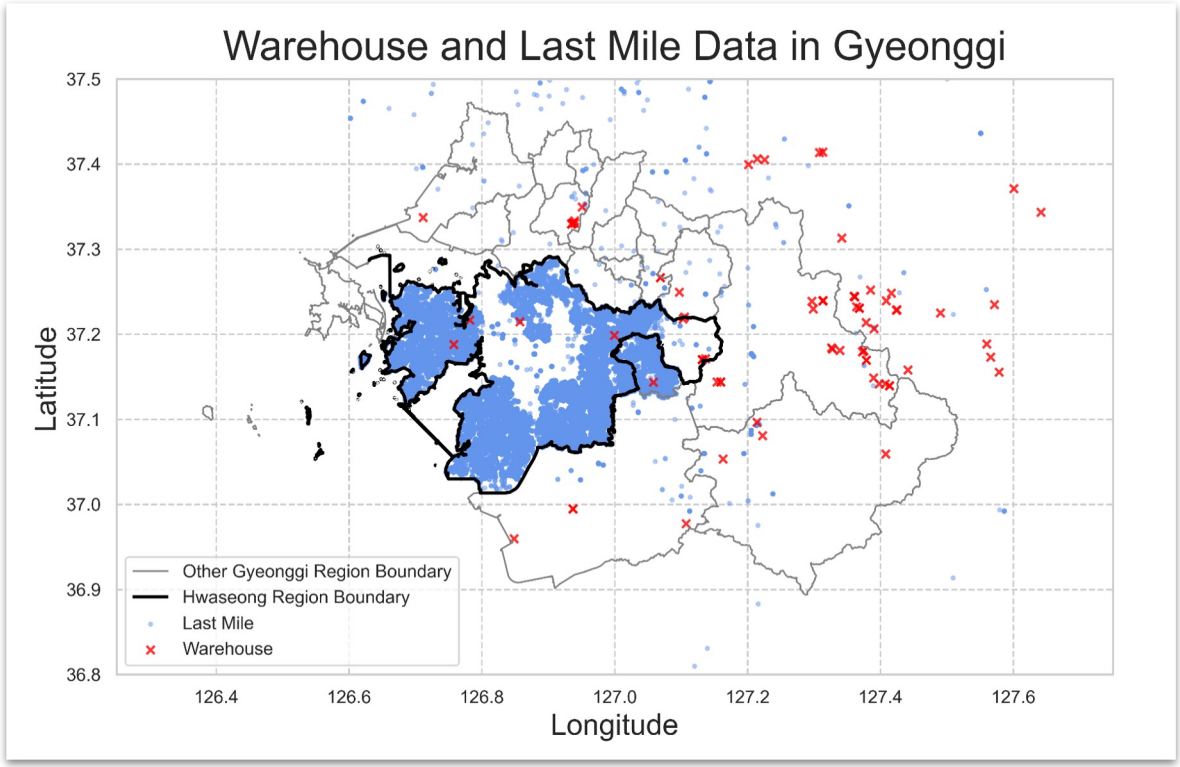
Proposed Methodology

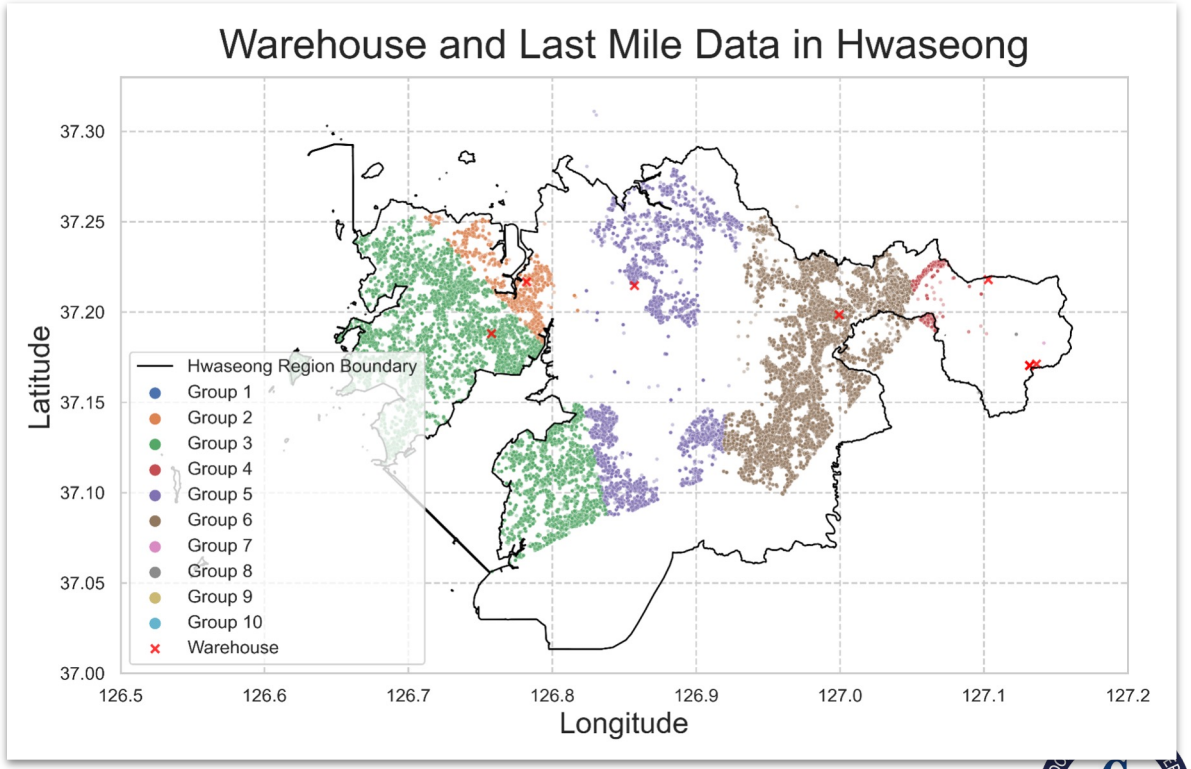
- Hypothesis Explanation



Proposed Methodology

- Logistics Demand Estimation
  - Last mile data of Hwaseong and Warehouse data of Gyeonggi-do
  - Some data were removed because of the potential possibility of came from other region.





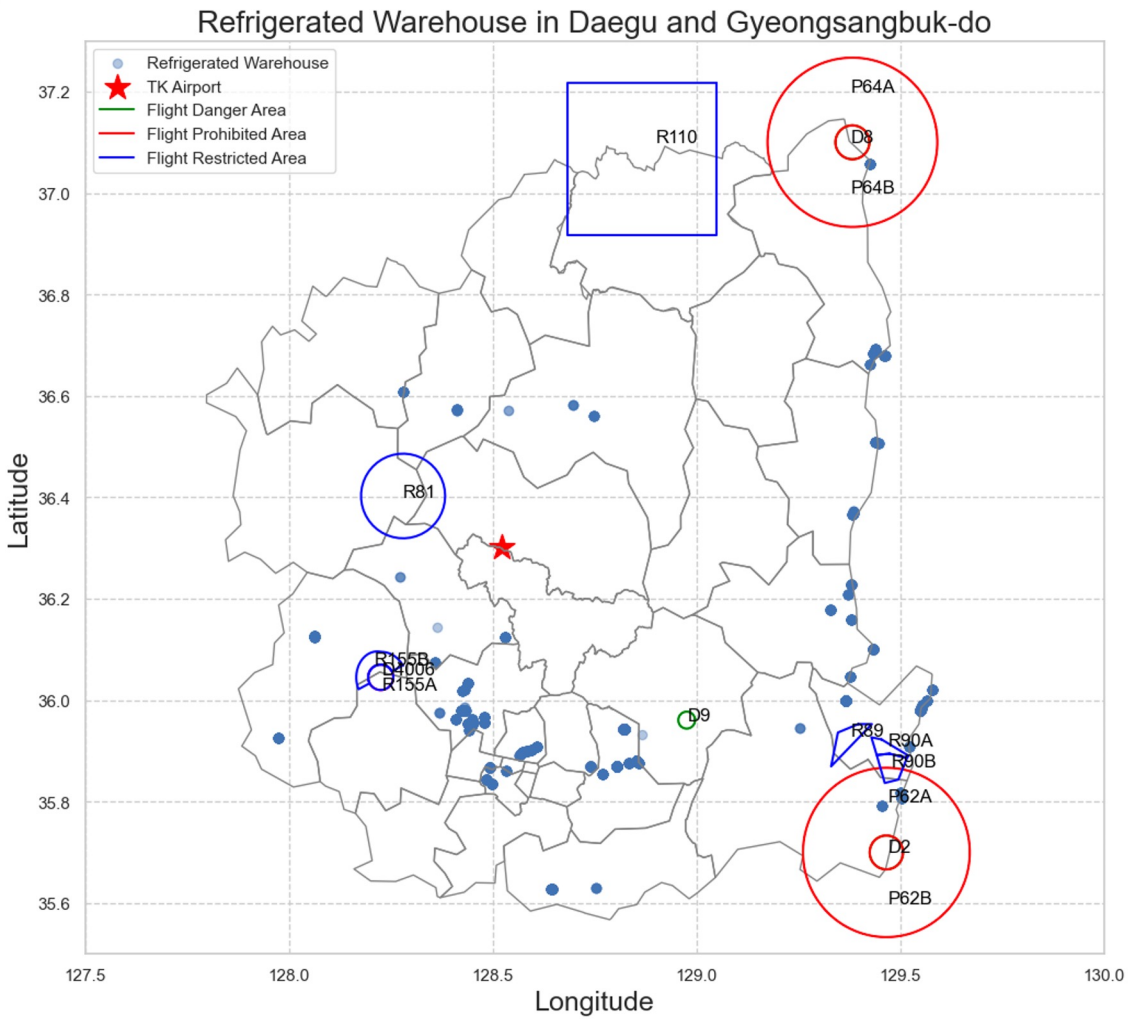
Proposed Methodology

- Logistics Demand Estimation
  - Linear regression between the warehouse capacity and logistics volume
  - $y = 46.67x - 75649.97$

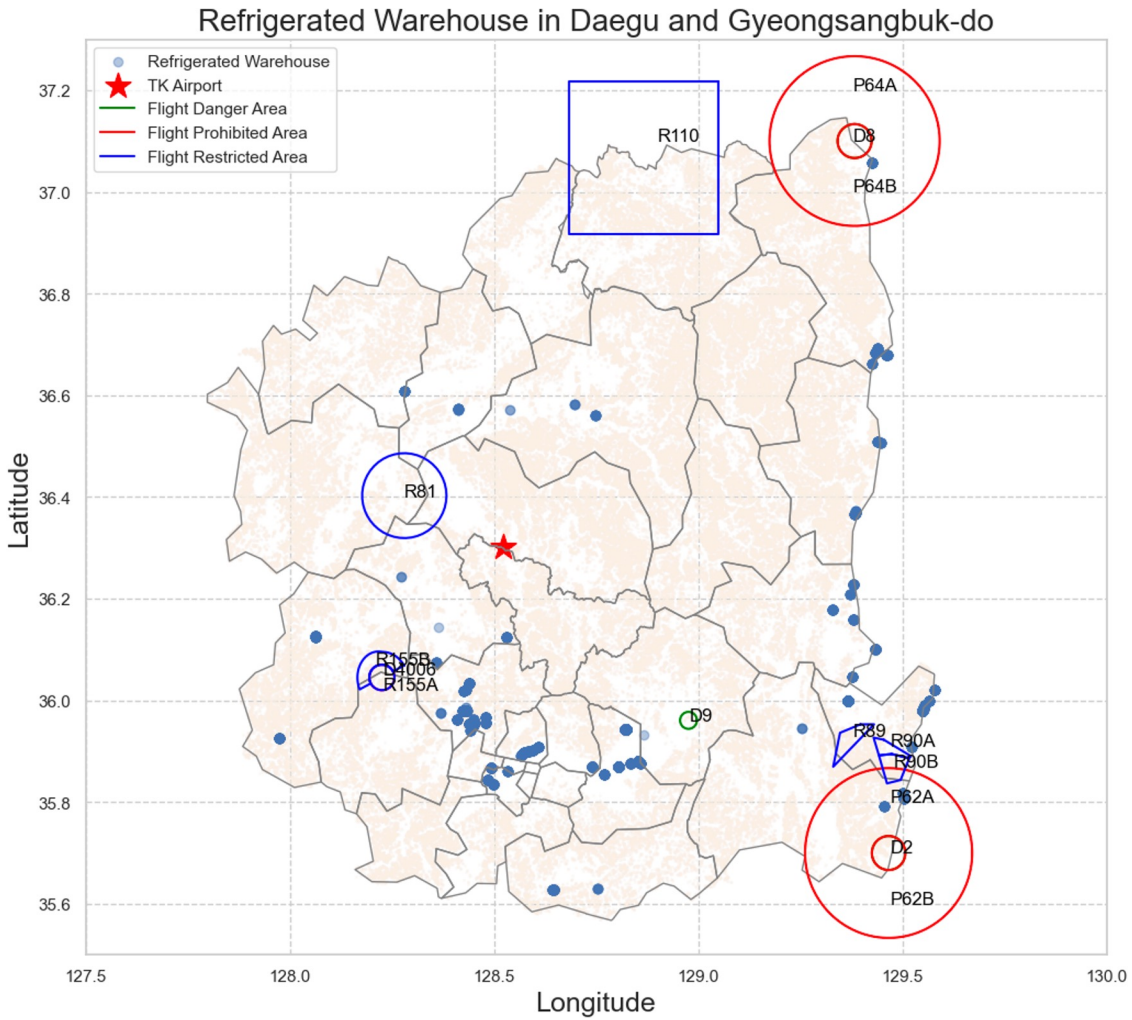
Assigning weight to the data points by the estimated relationship

Proposed Methodology

1. Locations of the warehouses(●) and the new TK airport(★) was marked.



2. Available slopes were marked on the map.



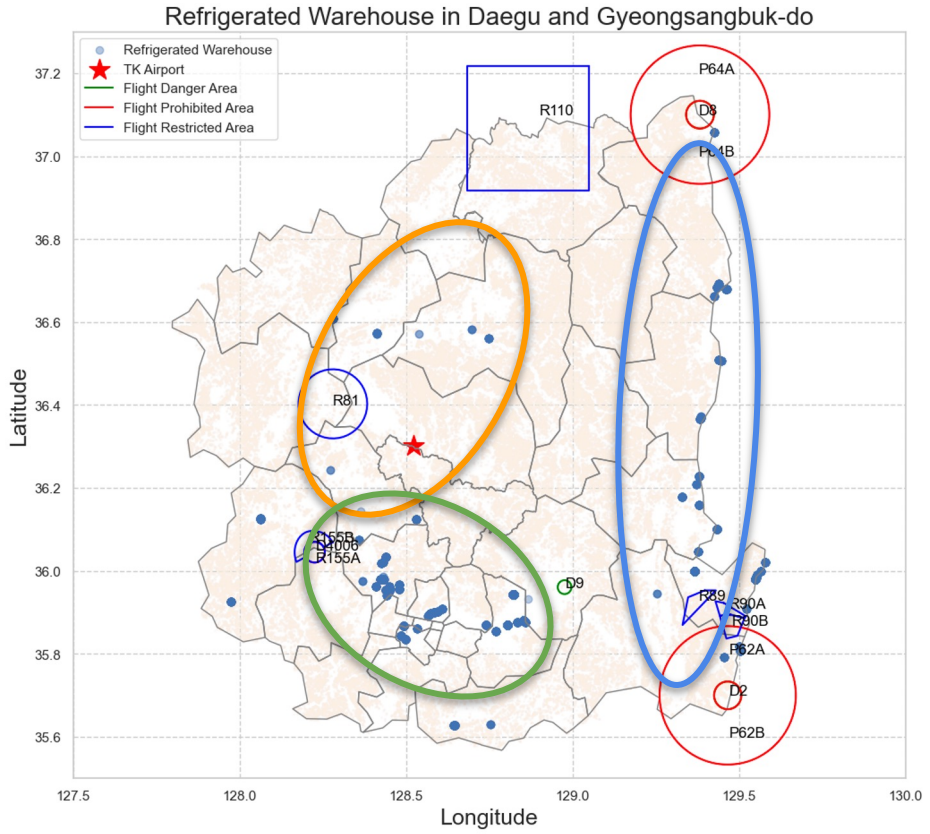
Proposed Methodology

- The K (number of clusters) for K Means implementation was determined by…

Eye inspection

K was determined by the visible number of clusters

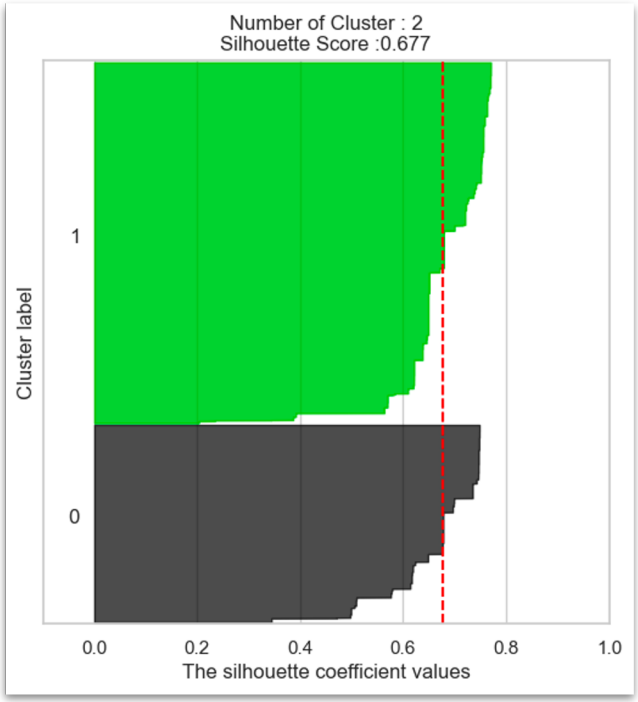
⇒ K = 3

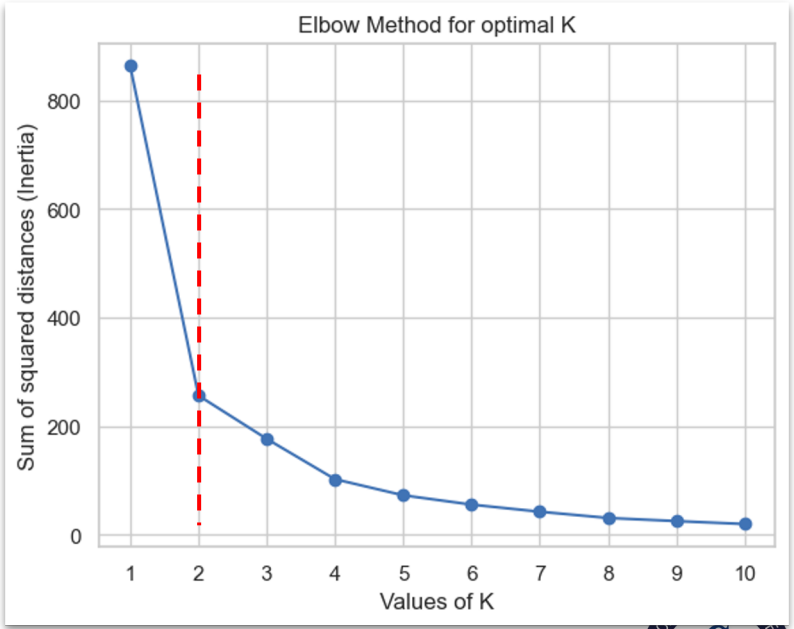


Silhouette method & Elbow method

K was determined based on the highest silhouette score and inertia

⇒ K = 2





Proposed Methodology

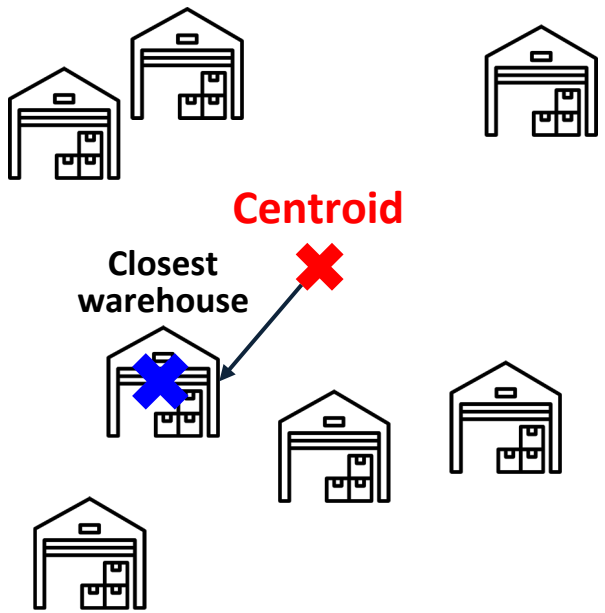
- Adjustment of vertiport candidate locations

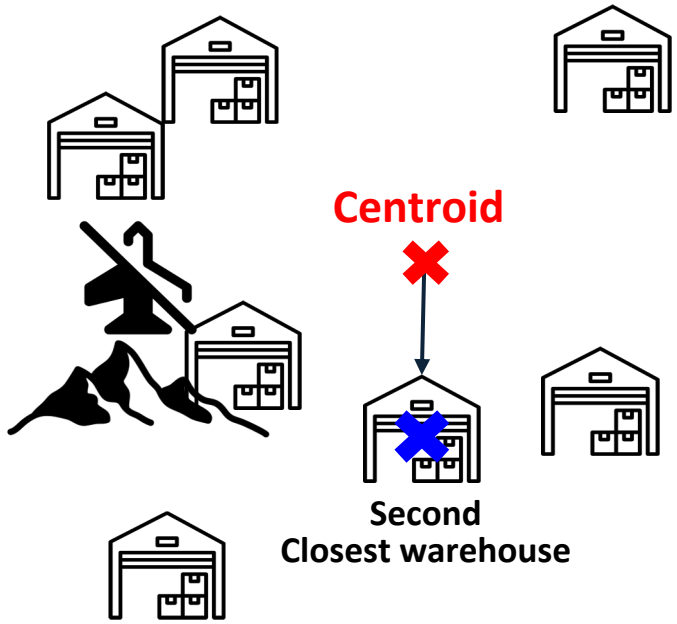
Adjust vertiport candidate to its closest warehouse

⇒ **Guarantees Ground Traffic Connectivity**

If the adjusted centroid overlaps with flight restricted areas or locations with high slope
→ adjust the location of centroid to the second closest warehouse

⇒ **Guarantees avoiding constraints**

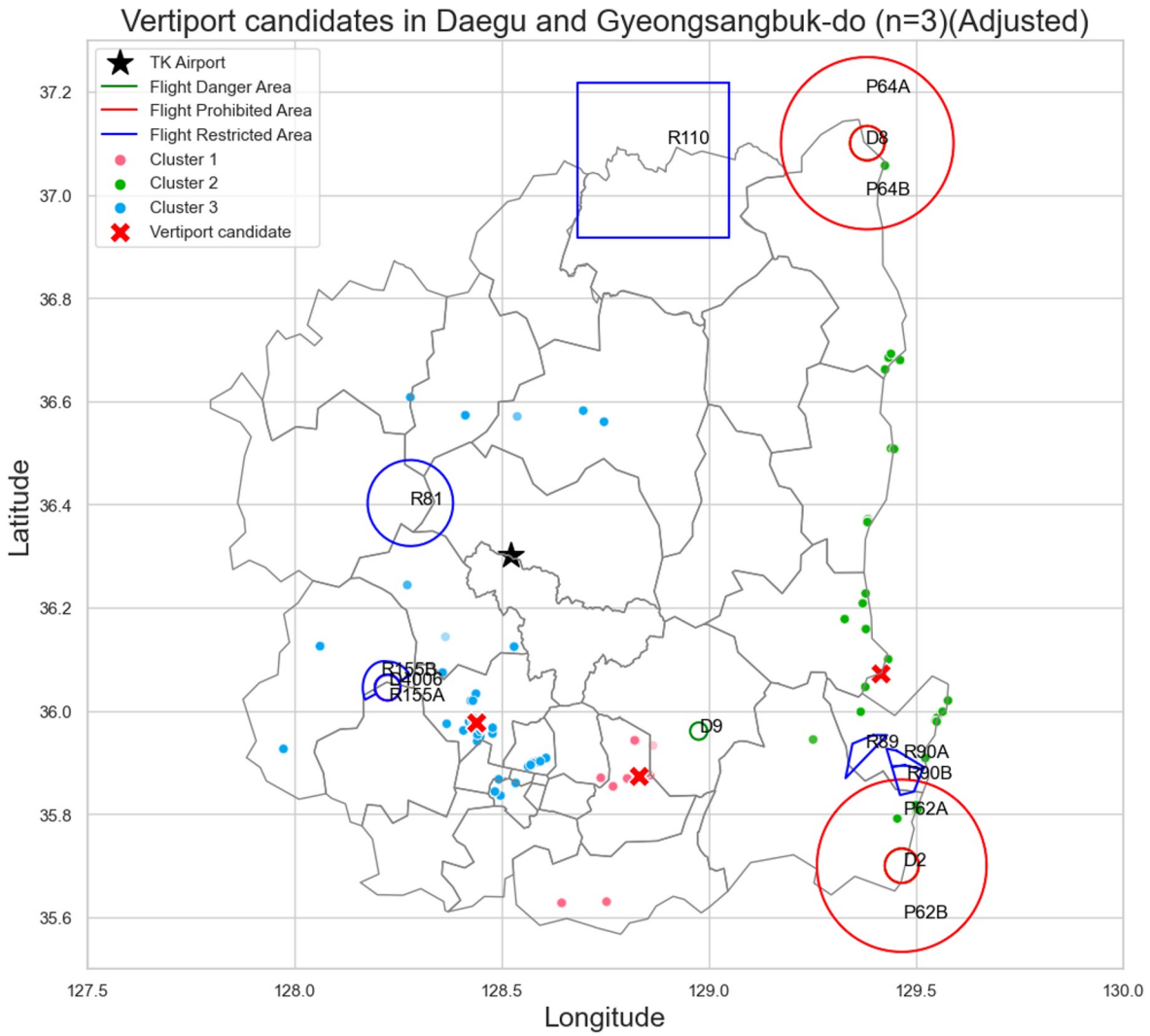


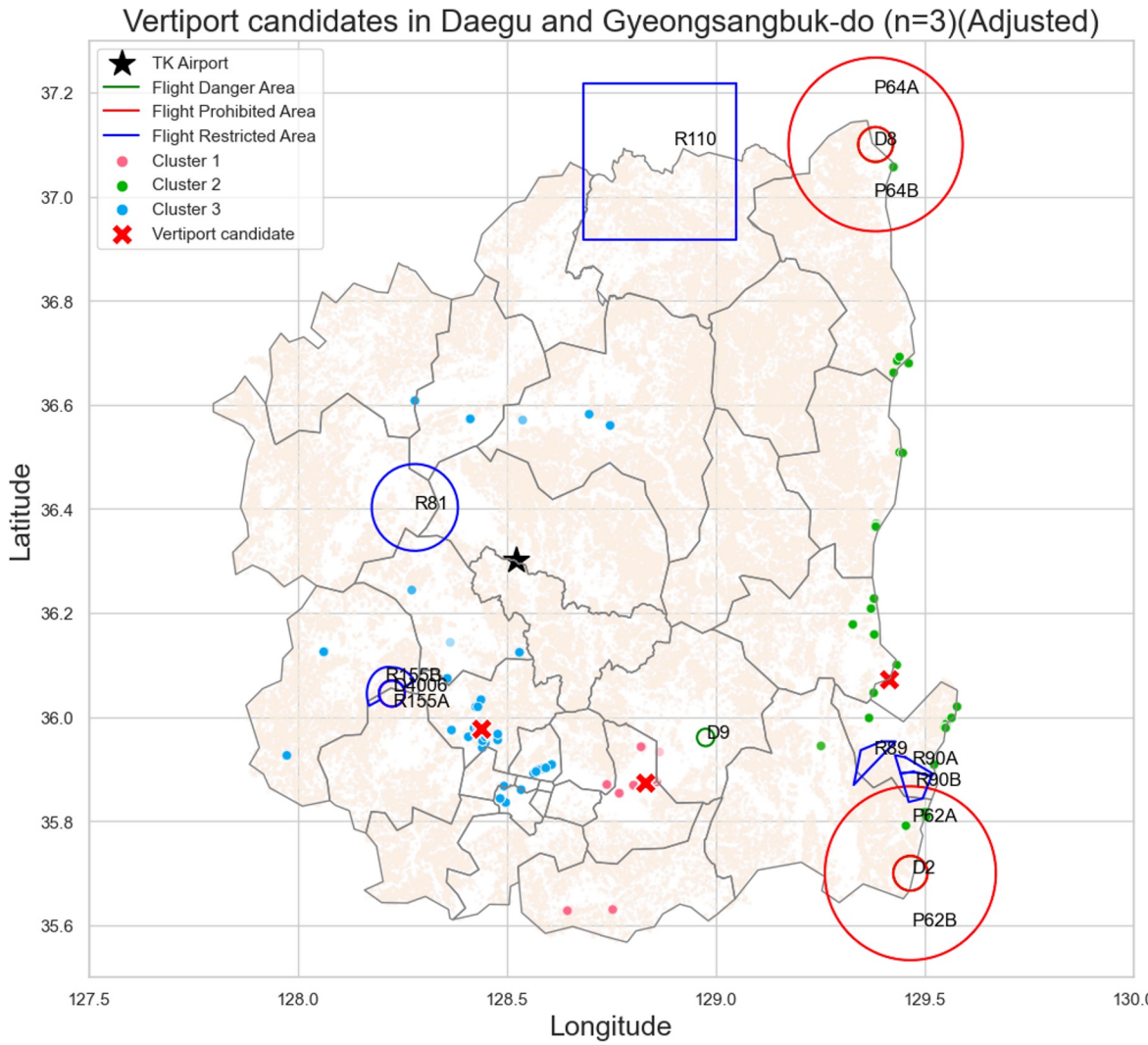


Preliminary Results

Preliminary Results

- Result of K-Means clustering with **adjusted** vertiport candidates (K = 3)

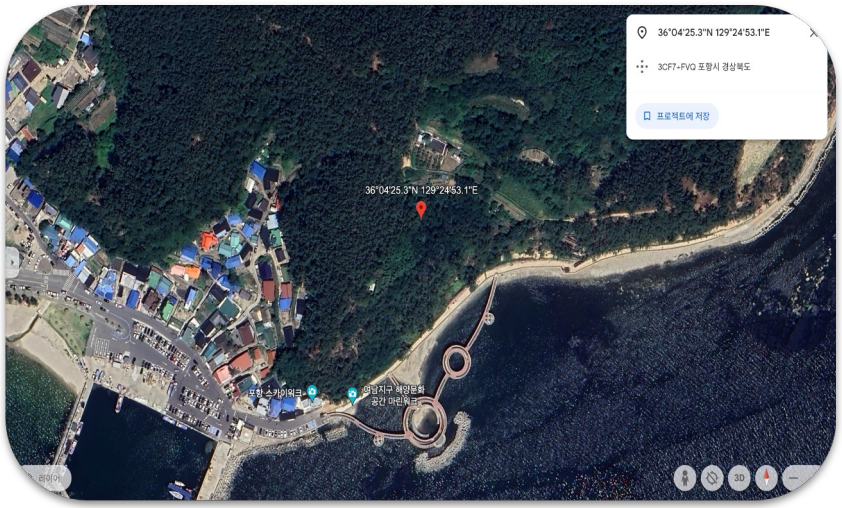




Preliminary Results

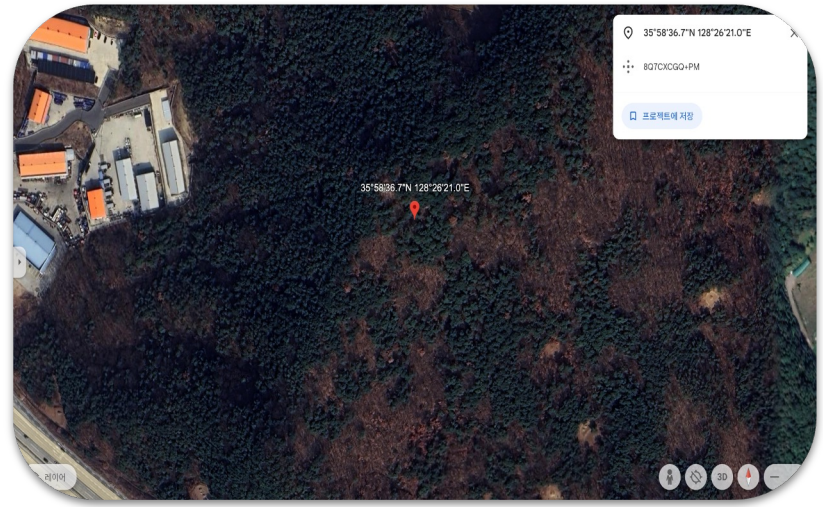
Centroid 1

경상북도 경산시 진량읍 신상리 1190-7



Centroid 2

경상북도 포항시 북구 여남동 59

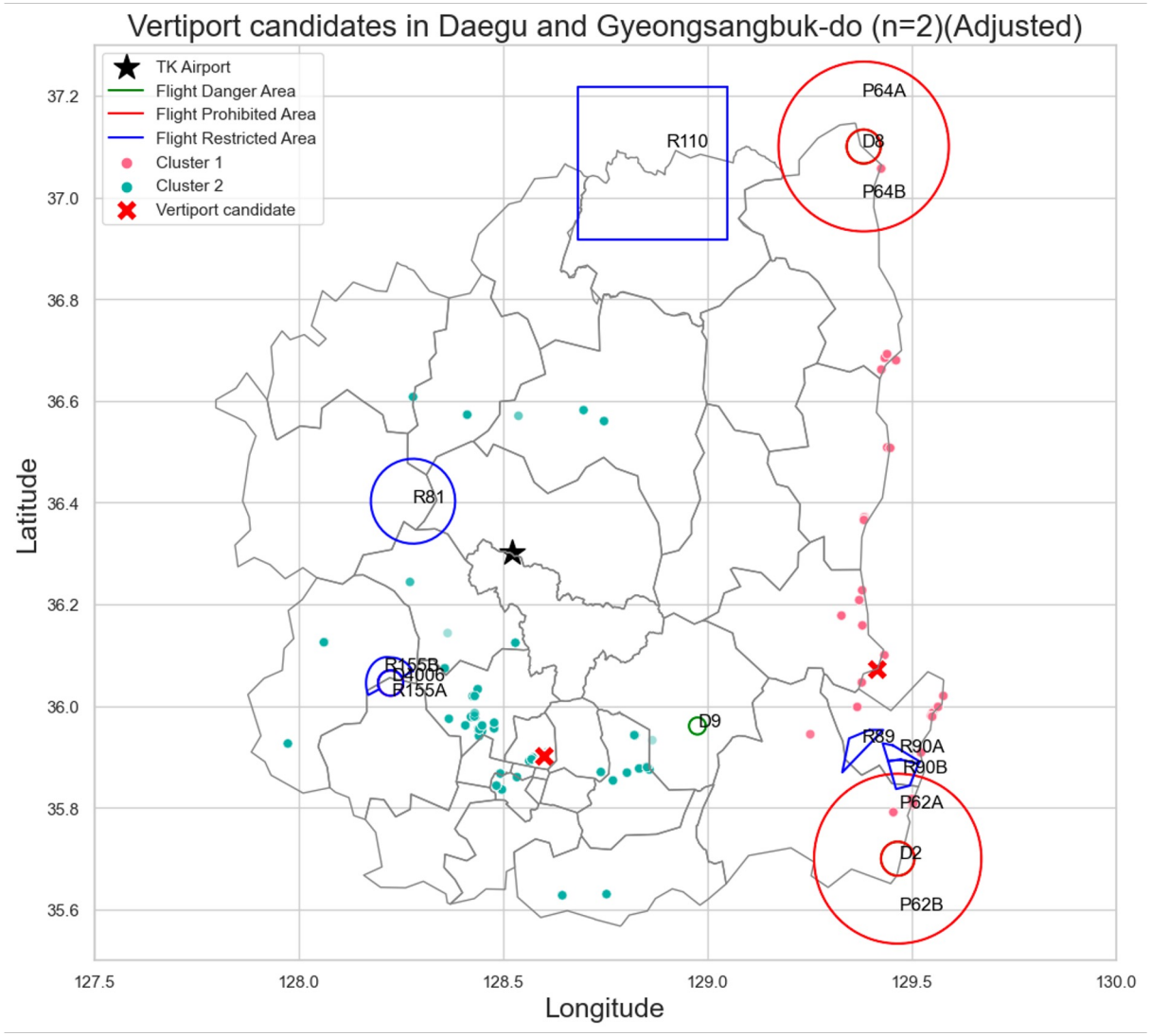


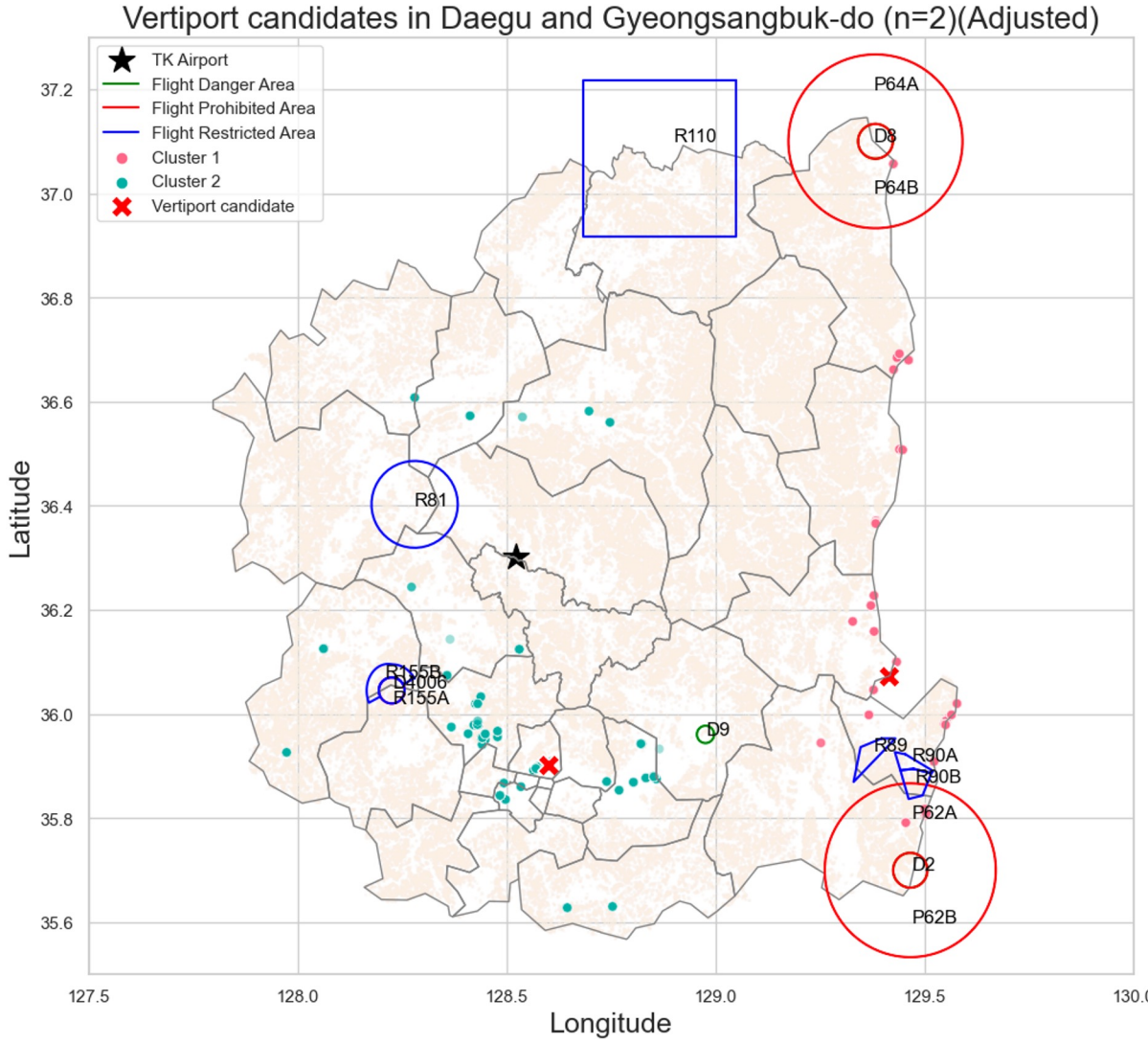
Centroid 3

경상북도 칠곡군 지천면 연화리

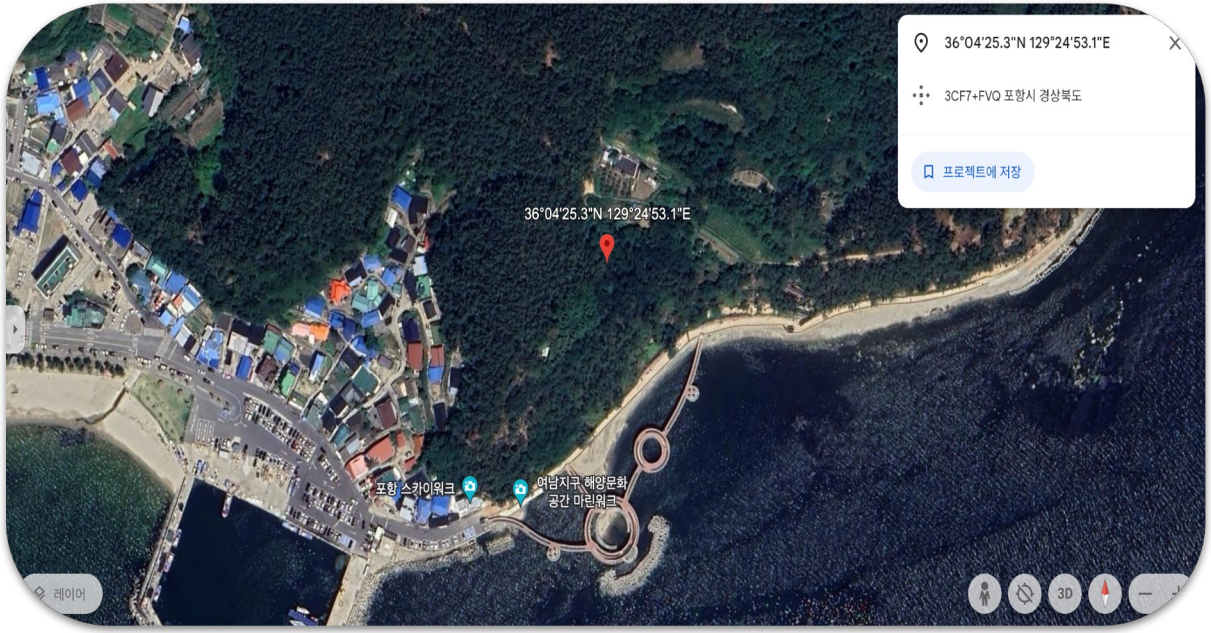
Preliminary Results

- Result of K-Means clustering with **adjusted** vertiport candidates (K = 2)





Preliminary Results



Centroid 1

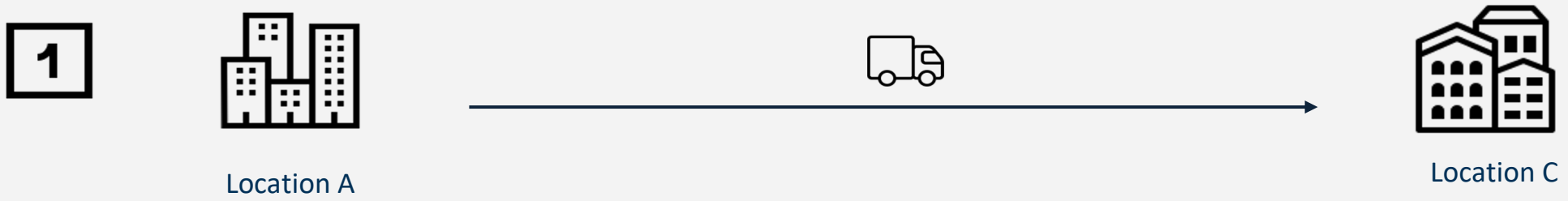
경상북도 포항시 북구 여남동 59

Centroid 2

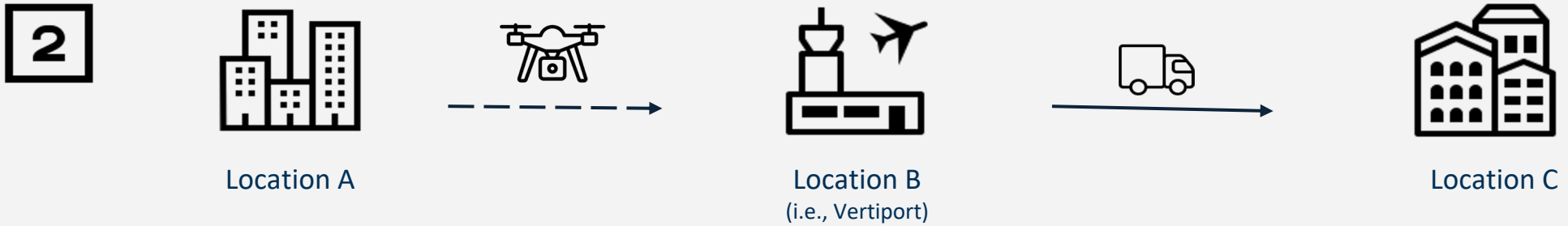
대구광역시 북구 산격동 549-1

Hypothesis 2

Approach 1: Measure time taken to directly travel from location A to C by KIA ‘Bongo 3’



Approach 2: Measure time taken to travel from location A to B by the ‘Alia250’ vehicle and travel from location B to C by KIA ‘Bongo 3’.



Hypothesis 2: “If we find the best vertiport placement, travel time will reduce significantly.”

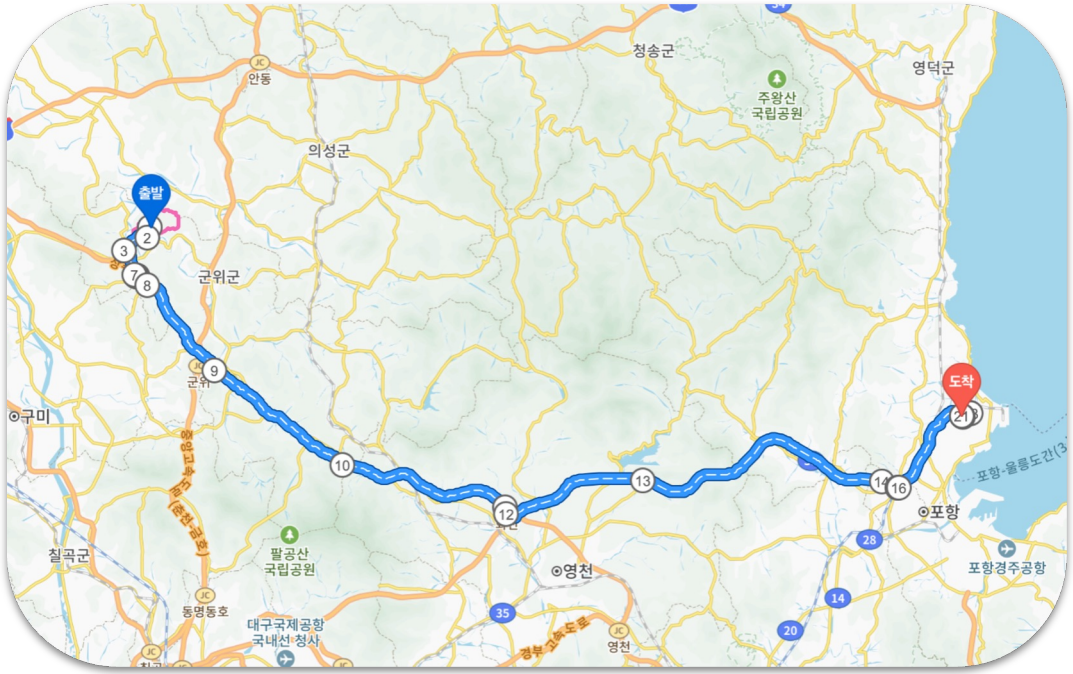
Hypothesis 2

- We estimated the travel time by car using the **Korean mobile navigation app** such as Kakao Map/Naver Map
- We estimated the travel time by Alia250 by taking **80% of its top speed (138 miles/hour)** as its travel speed, assuming that it travels **linearly**.

Aircraft Type	eVTOL passenger and cargo aircraft
Capacity	1 pilot and 4 passengers
Range	402 km
Payload	1,400 lbs (635 kg)
Electric motors	5
Battery charging time	50min ~ 1 hour
Flying time	average 88 min
Cruising Speed	274 km/h

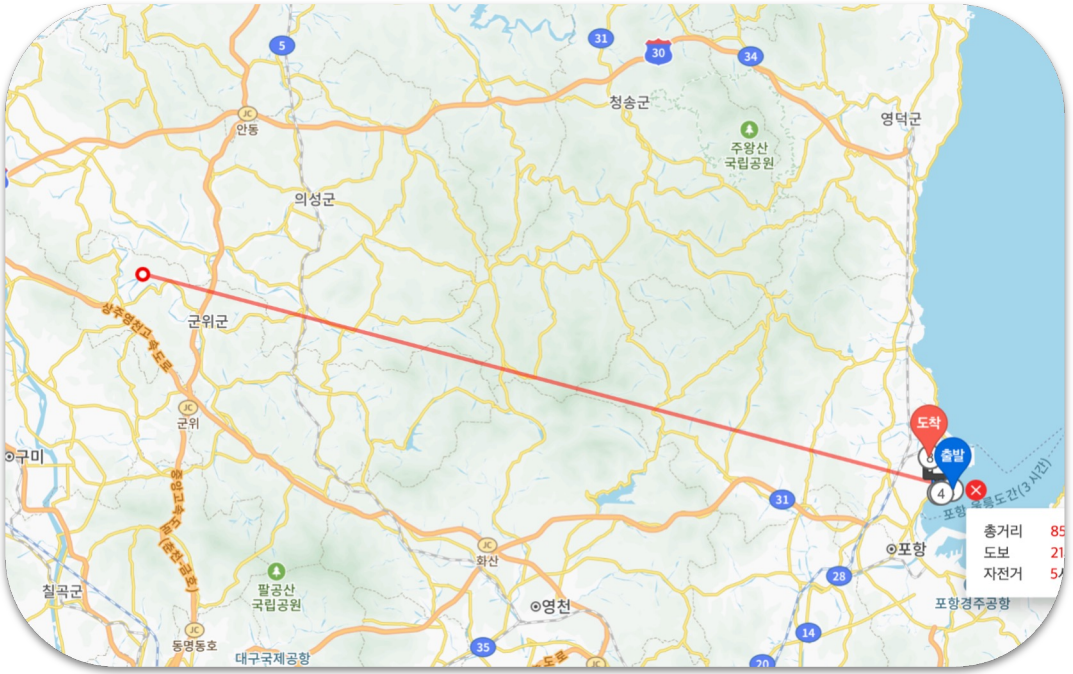
Hypothesis 2 Validation

Approach 1 (As is)



Total Travel Time: **91 minutes**

Approach 2 (To be)



23.5 minutes(UAM) + 16 minutes(Bongo)
Total Travel Time: **39.5 minutes**

56.6% Reduction in Travel Time!

Limitations, Future Works and Publication

Limitations and Future Works

- **Limitations**
  - Lack of consideration of certain variables:
    - Transmission Towers
  - Assumption that the correlation between ‘Warehouse Area’ and ‘Logistic Demand’ would be the same in all cities/regions (Hwasung and Gyeongsangbuk-do).
- **Future Work:**
  - Consider large scale infrastructures such as transmission towers
  - Instead of inferring ‘Logistic Demand’, utilize a dataset that directly measures the ‘Logistic Demand’.
  - Logistics Route Optimization could be incorporated into future studies
  - Explore UAM as the Last/First Mile Logistics mode of transportation
  - Explore with a different UAM vehicle (other than Alia250)
  - We need to adapt logistic demand estimation as weight to the K-means algorithm

Work Publications

- **Looking forward for publication**
  - The Korean Society for Aeronautical and Space Science (KSAS) (2024 Apr. 3rd~ 5th)
  - American Institute of Aeronautics and Astronautics (2023 Jan. 10th)

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9. Jeong and Hwang. (2021). Selection and Evaluation of Vertiports of Urban Air Mobility (UAM) in the Seoul Metropolitan Area using the K-means Algorithm. *한국항행학회논문지,* 25(1), 8-16.

THANK YOU