Drone-delivery Using Autonomous Mobility: An Innovative Approach to Future Last-mile Delivery Problems

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Abstract – **Drone-delivery is seen as a possible solution to future last-mile delivery problems. Meanwhile, autonomous mobility allows dynamic human transportation within a city, which solves future traffic complications. The purpose of this paper is to propose an innovative delivery concept called Drone-delivery using Autonomous Mobility (DDAM). DDAM combines drone-delivery with autonomous mobility, to simultaneously solve three problems of the future cities: (1) high demand of delivery (2) short delivery lead-time and (3) complex traffic congestions. Using the Design Science Research Guideline the concept is illustrated and evaluated based on interviews with experts from relevant industries. The results indicate that the DDAM concept is more feasible as an alternative delivery method in high-demand seasons. The research reveals a high-potential for utilizing autonomous mobility in last-mile delivery.**

Keywords – **Autonomous mobility, drone-delivery, last-mile delivery, sharing economy.**

I. INTRODUCTION

As the E-Commerce industry grows, more complex challenges arise for last-mile distribution; customers expect shorter delivery time from businesses, while demanding more orders. [1] Therefore, current research on last-mile delivery focuses on solving the following problems: (1) fulfilling high demand of orders and (2) delivering the goods to the customer with shorter lead time. However, considering that 65% of the world's population will live in urban cities by 2050, the logistics industry will also have to consider future city problems, such as insufficient transportation capacity.[2] Hence, the major problem of future last-mile delivery is not only limited to shortening delivery time and fulfilling customer demand, but also minimizing the use of on-road transportation for flexible transportation networks.

Drone-delivery

As an approach to solve future last-mile delivery complications, drones are being researched and developed for delivery purposes. Drone-delivery is spotlighted by industries because of its three advantages: (1) autonomous operation, (2) avoidance of traditional traffic network and (3) velocity. [3] However, the concept faces challenges in technological and social aspects. [4] Technologically, advanced developments on endurance and safety are necessary to fulfil orders from customers in far distance. Besides, social concerns on the exposure of numerous drones in the sky arise.

To mitigate those concerns, [5] studied the efficiency and feasibility of a concept that integrates drone-delivery and traditional truck-delivery. In this concept, drone-delivery is simultaneously conducted with truck-delivery, assuming that drones are faster than trucks. Compared to the original drone-delivery method, the concept shortens drone route and delivery time. Though the concept reduces truck usage compared to a traditional truck-delivery method, trucks are still used solely for delivery purposes, which does not fully address traffic congestions in future cities. As an alternative, one possible solution for this issue is using the dynamics of the sharing economy.

Sharing Economy & Autonomous Mobility

To soothe the increasing pressure on city infrastructure, the sharing economy allows sustainable consumptions of resources. For instance, crowdsourcing uses everyday people to solve existing problems, which utilizes underused resource for particular needs. Moreover, the sharing economy in transportation is succeeding with free-floating car-sharing platforms, where people consume resources together. [6] Companies such as Car2go, ZipCar, DriveNow and Evo have over 3 million users around the globe and it is expected that 22 million users will actively use car-sharing services in Europe and North America by 2020. [7]

Assuming the technological development of autonomous driving, various transportation methods such as taxis, crowdsourced transportations and car-sharing platforms will be no longer considered as separate terms but will represent one concept: autonomous mobility. In 2017, Daimler portraited the future of mobility through the 'smart vision EQ', a fully automated and shared urban traffic method. [8] Hence, research expects that 90% of overall vehicles could be replaced by fully autonomous vehicles in the future. [9] Thus, autonomous mobility is leading a massive transformation in future transportation.

Purpose of research

The purpose of this paper is to propose a new concept by integrating drone-delivery and autonomous mobility, which aims to concurrently solve future last-mile logistics problems of customer demand, delivery time, and traffic. Accordingly, the new concept called Drone-Delivery using Autonomous Mobility (DDAM) is evaluated by applying the Design Science Research Guideline (DSRG).

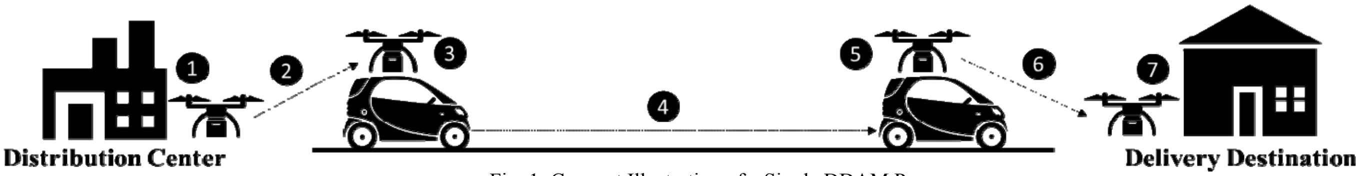

Fig. 1: Concept Illustration of a Single DDAM Process

II. METHODOLOGY

Design Science is a problem-solving paradigm, which seeks to extend the boundaries of scientific thinking, by creating a non-existing artifact. [10] To develop the DDAM concept, this paper follows the *Design Science Research Guideline (DSRG)* as proposed by [10]. The DSRG investigates innovative concepts from both the scientific and practical view and follows seven guidelines outlined in TABLE I.

TABLE I
Design Science Research Guideline

Steps	Description
Step 1: Design as an Artifact	The new concept is illustrated and elaborated.
Step 2: Problem Relevance	The relevance of future last-mile delivery problems is explained
Step 3: Design Evaluation	The concept is evaluated through a SWOT analysis.
Step 4: Research Contributions	The concept examines the contribution to research in the field of last-mile delivery, drone-delivery and autonomous mobility.
Step 5: Research a Rigor	A rigorous evaluation was conducted through interviewing experts from relevant industries.
Step 6: Design a Search Process	A study on drone regulations is conducted.
Step 7: Communication of research	The concept was presented to technology- and management-oriented audience.

III. RESULTS

Step 1: Design as an Artifact

A single-delivery process of the DDAM concept consists of seven physics steps (see Fig. 1):

1. Drone picks up package from *Delivery Center (dc)*
2. Drone flies to autonomous mobility vehicle
3. Drone connects to roof of autonomous mobility vehicle
4. Autonomous mobility vehicle drives, while drone stays idle
5. Drone disconnects from roof
6. Drone flies to *Delivery Destination (dd)*
7. Drone drops down package at *Delivery Destination*

The primary objective of the concept is to deliver a package from the *Distribution Centre* to the *Delivery Destination*. Autonomous vehicles, which are primarily used to transport passengers to the passengers' destination, also transports drones. The autonomous vehicle does not change its original route because the concept seeks to utilize existing resources to solve traffic problems. In other words, drones use autonomous mobility vehicles as an intermediate transportation method to deliver packages to *Delivery Destinations*.

To give further explanations of the concept, Fig. 2 illustrates a single delivery process using the concept. The drone connects to the autonomous vehicle at node *i* and disconnects from the vehicle at node *j*, which are the location coordinates for step 3 and step 5 of Fig. 1.

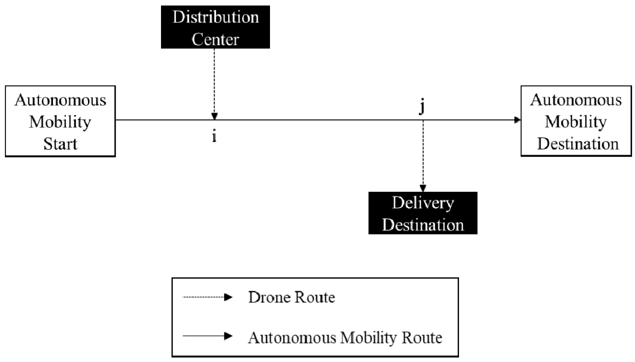

Fig. 2: Explanation of DDAM with connecting and disconnecting nodes

The distance from the *Delivery Center* to node *i* is the flying distance in step 2 of Fig. 1. The distance from node *i* and node *j* is the driving distance for the autonomous vehicle in step 4 of Fig. 1. The distance from node *j* to the *Delivery Destination* is the flying distance for step 6 of Fig. 1. Thus, the total delivery distance (TDD) is given as:

$$TTD = D(dc,i) + D(i,j) + D(j,dd) \quad (1)$$

Also, the drone-flying distance (DFD) is formulated as:

$$DFD = TTD - D(i,j) \quad (2)$$

To minimize the drone-flying distance, the coordinates of two nodes should be calculated: (1) connecting node *i* and (2) disconnecting node *j*. Connecting node *i* is calculated from the shortest flying distance from the *Delivery Center* to the autonomous vehicle. Disconnecting node *j* is calculated from the shortest flying distance from the autonomous vehicle to the *Delivery Destination*.

Moreover, it is necessary to explain how the concept will be practiced within a future city, where multiple deliveries exist. As shown in Fig. 3, a *Distribution Center* is located within the city and there are five *Delivery Destinations*. There are multiple *Autonomous Mobility*

Routes within the city, heading to the destination of the autonomous mobility users. When the packages of the orders are ready to be delivered in the *Distribution Center*, the most optimal autonomous mobility route is calculated for each destination. As the autonomous vehicles pass by the *Distribution Center*, the drones carrying packages, fly to the autonomous vehicle on the connecting coordinates of *Drone Route* and *Autonomous Mobility Route*. The autonomous vehicles will drive on their *Autonomous Mobility Route* with the drones on top of the roof. Finally, the drones disconnect from the vehicle on the closest point of the *Delivery Destination*.

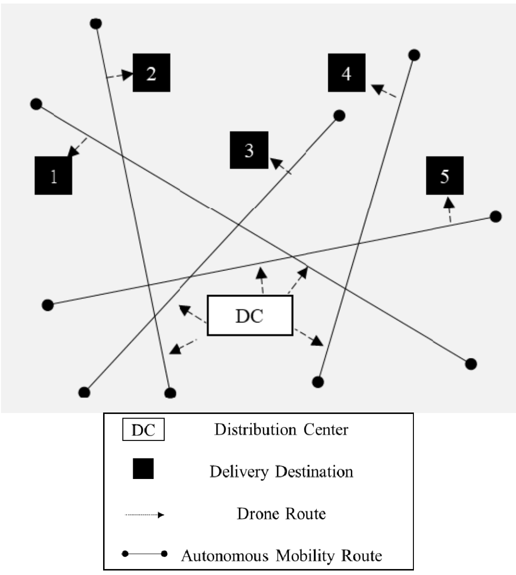

Fig. 3: Multi-delivery process of DDAM

Step 2: Problem Relevance

Current last-mile delivery research focus only on delivery time and customer demand. However, it is necessary to also consider future traffic congestions because traditional last-mile delivery increases traffic. Hence, the DDAM concept provides a cutting-edge approach to solve future traffic and last-mile delivery issues simultaneously through innovative technologies such as drones and autonomous vehicles. Whereas the drones enhance delivery operation with speed, autonomous vehicles are utilized as a middle transportation method of the delivery process, which benefits the future traffic complications.

Step 3: Design Evaluation

In this section, a SWOT analysis will be conducted as a self-evaluation of the DDAM concept. Thus, the authors seek possible strengths, weaknesses, opportunities and threats (SWOT) of DDAM, as shown in TABLE II.

Step 4: Research Contributions

First, DDAM attempts to improve last-mile deliveries by shortening delivery time and increasing delivery efficiency. Second, safety and social challenges of current drone-delivery concepts are solved by decreasing the drone operation distance. Lastly, the DDAM contributes to autonomous mobility by adding value onto its original concept. In DDAM, the initial concept of autonomous mobility is further utilized by using the vehicles as intermediate transportation methods for drone-delivery, which eventually improves both drone-delivery and last-mile delivery operations.

TABLE II
SWOT Analysis for DDAM

SWOT	Description
Strengths	- Short drone operation - Usage of existing resources - Elimination of delivery vehicles
Weaknesses	- High operation cost - Uncertainty of autonomous mobility route - Drone-delivery receiving mode
Opportunities	- Growth of E-Commerce - Growth of mobility - Development of commercial drones - Development of autonomous driving - Increasing traffic congestions
Threats	- Drone Regulation - Unalignment of last-mile delivery and autonomous mobility service providers - Weather conditions

Step 5: Research a Rigor

To rigorously evaluate the new DDAM concept, five interviews with experts in the following fields were conducted: *Battery*, *Drone-delivery*, *Last-mile Delivery*, *Autonomous Delivery* and *Autonomous Mobility*. The interviews seek to identify the feasibility, strengths, weaknesses, prerequisites and improvements of the DDAM concept. The results of the expert evaluations are shown in TABLE III. Also, the evaluations of experts are discussed in *Section IV*.

Step 6: Design a Search Process

Throughout the SWOT analysis in *Step 3* and Expert Evaluation in *Step 5*, it has been shown that the current regulations and legislations of drone operation are the key barriers for implementing DDAM. In this section, we search for current drone regulations of the *US Federal Aviation Administration (FAA)*. [11] Firstly, drone regulations state that drones cannot be operated over people. However, to enable DDAM into practice, it seems necessary to operate nearby pedestrians and inhabitants. Secondly, drones are regulated for being flown from moving vehicles. Since the connection and disconnection phase of autonomous vehicles and drones require dynamic activities, either regulations would need to be mitigated or autonomous vehicles would be required to be idle during the connection and disconnection phase. Thus, current regulations limit DDAM from operation and changes to the drone regulations would be necessary in the future.

TABLE III
Expert Evaluation

Expert	Feasibility	Strengths	Weaknesses	Prerequisite	Improvement
Battery	- Overall concept is technologically feasible - Drone charging on roof is feasible - Feasibility of autonomous mobility questioned - Battery technology is feasible for the concept	- Shortening drone distance simplifies engineering, reduction of cost per drone and battery charging time - Utilization of existing resources	- Heavy reliance on autonomous mobility commercialization - Safety issues in drone-delivery: communication, controlling method - Package capacity	- Full IoT development in automotive industry - More accurate information of car location and traffic. - Information on customer's schedule	- Usage of 'Connected Cars' instead of autonomous mobility - Usage of public transportation instead of autonomous mobility
Drone-delivery	- Feasibility of drone-delivery is difficult - Technologically not feasible to drive with drones on roof	- Utilization of existing resources	- Current drone-delivery problem: customer receiving method, noise, package security, regulation, payload - Minimizing drone route - Danger of drones on roof	- Automation of drone controlling - Larger capacity of vehicle battery - Solution to current drone-delivery problems	- Usage of vans instead of cars - Maximize drone operation - Focus on delivery accuracy than delivery speed
Last-mile Delivery	- Concept is feasible only with the commercialization of autonomous mobility - Feasibility of meeting high demand is difficult	- Reduces drone-operation distance - Utilization of existing resources	- Weak on high-drop factor - Demand of car-sharing does not meet demand of packages	- Information of destination receiving time - Communication between drone and customer	- Usage of transportation with regular routes - Customer confirmation method
Autonomous Delivery	- Technologically feasible - Not feasible for delivery		- Complex vehicle routing - High investment cost - No advantage of drones - Drones still cause safety and social problems	- Physical infrastructure - Mobile infrastructure - Coordination in backend	- Usage of other technology instead of drones: Robotic parcels
Autonomous Mobility	- Technologically feasible - Operation is possible - Autonomous mobility will be commercialized	- Utilization of existing resources - Eases future traffic problems	- Not beneficial for delivery companies - Complex traffic management - DDAM depends on large-scale autonomous mobility	- Partnership with cities - Legislations and regulations - Cooperation of companies from different industries	- More feasible for rural areas, with long-distance - Parcels can be delivered with autonomous vehicles directly, without human transportation

Step 7: Communication of Research

DDAM was presented in a scholar seminar of 'The Korean Engineers and Scientists Association (KESA) in Germany'. The group consists of active researchers and experts working in the field of science and engineering. Being asked to evaluate the feasibility of the DDAM concept out with maximum 5 points, the 16 seminar participants gave an average of 3.8 points. In addition, whereas 4 participants questioned the commercialization of autonomous mobility, 3 participants suggested to use public transportation because of its regular and predictable vehicle routing.

IV. DISCUSSION

All experts from *Step 5* commonly viewed DDAM as a technologically feasible concept. The technology of both drone-delivery and autonomous mobility is already developed. Further, the experts together praised that using existing resources, such as autonomous mobility, has a strong potential to benefit the future of last-mile delivery and to reduce traffic congestions. The *Autonomous Mobility Expert* expects mobility concepts to be a large part of human transportation. However, the expert also commented that transportation mobility concepts are only active in high-peak time slots, such as when people go to or come back from work. Hence, the under-utilized time of transportation mobility concepts could be further utilized by various businesses, such as last-mile delivery.

Although, the experts had same understandings of the technological feasibility and utilization of existing resources, they provided contradicting opinions on two topics: (1) *drone-distance reduction* and (2) *autonomous mobility commercialization*.

Drone-Distance Reduction

In the SWOT analysis, we stated that shortening drone-distance would reduce the safety risk and social concerns of drone-delivery. Supporting the our opinion, the *Battery* and the *Last-mile Delivery Experts* emphasized the importance of shortening drone distances as this enables drone operation with smaller motors and battery as well as lower cost per drone. Moreover, it benefits the society by decreasing the amount of drone appearances in the air.

However, the *Drone-delivery* and *Autonomous Delivery Experts* refuted the positive opinions of shortening the drone distance. They stated the importance of maximizing drone operation in a delivery because drones benefit from the fast speed by flying over on-road traffic. Although three experts gave positive evaluations on the reduction of drone-distance, the *Drone-delivery* and *Autonomous Delivery Experts* pointed out that drones are not fully beneficial when integrated to autonomous mobility, as this limits the drone's biggest advantage: speed. Hence, further research seems necessary to compare the overall efficiency of drone-delivery and DDAM.

Autonomous Mobility Commercialization

Prospects towards autonomous mobility were also conflicted between evaluators. We expect autonomous mobility to be fully commercialized in the future. In contrast, two evaluators explicitly questioned the wide usage of autonomous mobility. The *Last-mile Delivery Expert* pointed out that the demand of autonomous mobility seems to be insufficient to the demand of delivery orders. Also, the *Battery Expert* suggested to use transportation methods with more regular routes, such as public transportation.

In response to the debate on the commercialization of autonomous mobility, the *Autonomous Mobility Expert*, who directly examines, develops and practices autonomous mobility concepts, confidently assured the commercialization of autonomous mobility, based on the company's research and future prospect. However, in order to fully operate the DDAM, a large fleet of autonomous vehicles would be needed.

Discussion Results

Reflecting rigorous evaluations and suggestions from experts, the concept seems to be more feasible as an alternative method for delivery in high-demand seasons, instead of a major delivery method. Also, delivering packages with autonomous mobility vehicles in off-peak time, when majority of people do not use autonomous mobility, will highly utilize the autonomous vehicles. The efficiency of drone operation in DDAM remains a major discussion among experts and it seems that an alternative method could have more potential in delivery processes. Therefore, as mentioned by the Autonomous Delivery Expert, using robotic parcels could abate the strict regulations and eliminate the risk of drone usage.

V. CONCLUSION

The DDAM concept was introduced, examined and evaluated by experts through the Design Science Research Guideline (DSRG). Through the seven guidelines, this paper gathered various opinions on DDAM as well as valuable insights to future last-mile delivery and traffic problems. First, using drones could increase the speed and flexibility of a delivery process, eventually enlarging delivery capacity. Second, autonomous mobility takes place as a middle process of a delivery, which reduces vehicles by adding value to existing transportation methods. However, there remains limitations for concept development, providing potential further research areas.

First, the concept evaluation was conducted by only five evaluators from two companies, which limited the research from gathering wider point-of-views. The evaluations were narrowly focused in the perspective of each expert's expertise, which enabled critical views from various focus areas but restricted the experts from evaluating the concept's overall idea. Second, DDAM is a combination of two futuristic features, which are not yet commercialized. Thus, the concept understanding of each expert could have varied, depending on personal insights to the futuristic features. Lastly, the concept was not numerically compared to any existing concepts.

Therefore, the concept can be further investigated and measured through a simulation model, which can be quantitively comparable to existing delivery concepts such as direct drone-delivery. The simulation model can refer to a specific city and use delivery rate, delivery time, drone-operation time, drone efficiency as KPIs, which can compare the overall delivery efficiency between DDAM and other delivery methods.

Finally, to practice DDAM into real life, it seems necessary for last-mile delivery and autonomous mobility companies to collaborate among each other. Mainly, the incentive of using autonomous mobility in a delivery process and the risk sharing would need to be negotiated. A shared platform would also be needed, thus relevant information, such as vehicle route, delivery time, delivery destination and traffic, could be freely exchanged. Providing new insights for solving future last-mile delivery and traffic problems, DDAM provokes the innovative thought of delivery concepts in the future and contributes to the connectivity of future society.

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