Unmanned Logistics System Using New Mobility Technologies

To solve social challenges such as labor shortages and the increasing number of parcels handled by the logistics industry, Kawasaki is working on new unmanned logistics solutions that combine air and land transport equipment with robotics technologies. To achieve it, Kawasaki is developing delivery robots, multi-purpose unmanned ground vehicles (UGV), and unmanned vertical take-off and landing (VTOL) aircraft.

Introduction

In the logistics industry, social challenges such as labor shortages, traffic congestion in urban areas, transport to rural areas, and an increasing number of parcels due to the rapid growth of electronic commerce have been becoming increasingly obvious recently. If logistics, which is essential as social infrastructure, does not function well, our lives become less convenient, and moreover, economic activity stagnates.

1 Background

A serious labor shortage presents a fundamental social challenge for the logistics industry. To address this, the government has suggested logistics DX and logistics standardization in its "Comprehensive Logistics Policy Outline for the 2020s [1]."

Logistics DX refers to the act of updating the conventional form of logistics through mechanization and digitalization. Mechanization refers to the act of automating human-intensive transport and warehousing work with machinery (automation or labor savings). Digitalization includes computerization of procedures and streamlining of operations through the use of matching systems and AI. Standardization of logistics is as important an effort as logistics DX.

To contribute to solving the logistics challenges that society faces, Kawasaki is developing technologies that offer new solutions with the primary aim of contributing to automation and autonomy in logistics DX.

2 Solution concept

To solve the logistics challenges that society faces, Kawasaki aims to offer unmanned cargo transport and transshipping without human intervention, by combining its robotics, mobility, and aviation technologies shown in **Fig. 1**, and seamless, unmanned logistics solutions as shown in **Fig. 2**.

Long-term, Kawasaki aims to achieve carbon-neutral transport by combining its energy and environmental solutions, looking ahead to solving not only logistics challenges but also the decarbonization challenges that society faces.

At present, as means of transport and of delivery in seamless logistics solutions, Kawasaki is developing delivery robots (shown in **Fig. 3 (a)**) as well as multi-purpose unmanned ground vehicles (UGVs) and unmanned vertical take-off and landing (VTOL) aircraft (shown in **Fig. 3 (b)**).

(1) Delivery robots

Kawasaki is developing robots that can not only deliver packages but also hand over and receive packages as well as perform light-duty work. This development combines the size and weight reduction technologies and suspension systems offering high running-through performance that Kawasaki has developed for motorcycles as well as the arm control and surrounding environment recognition technologies that Kawasaki has developed for robots. In addition to the logistics field, the company aims to apply these robots to other fields such as the manufacturing field as well as the medical and nursing care fields.

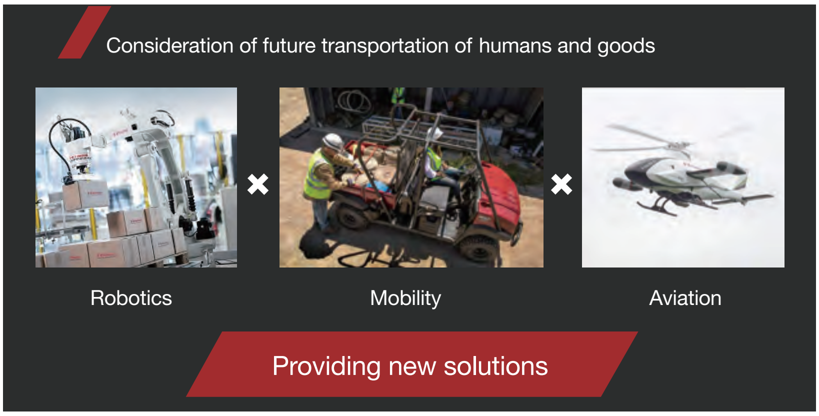


Fig. 1 Combination of Kawasaki's technologies that transform transportation of humans and goods

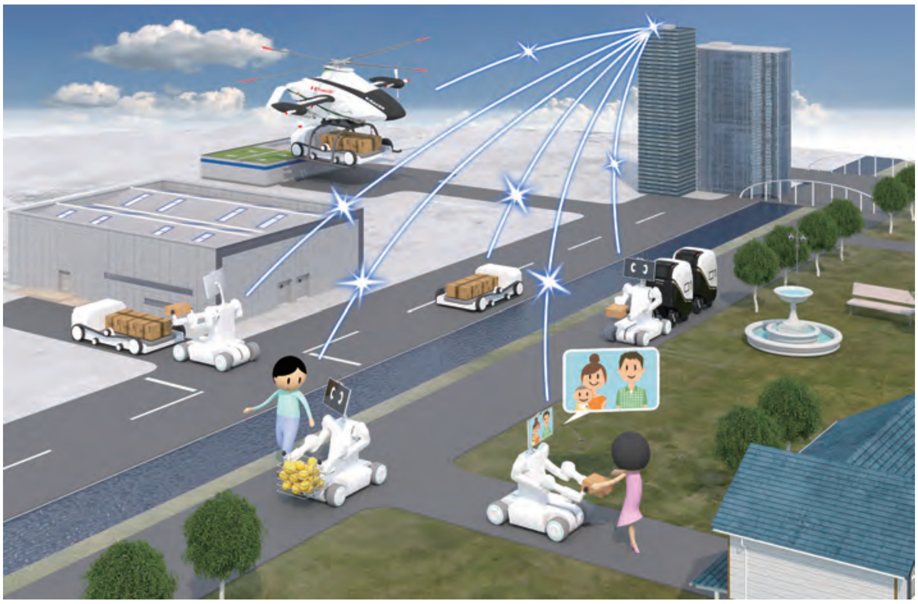
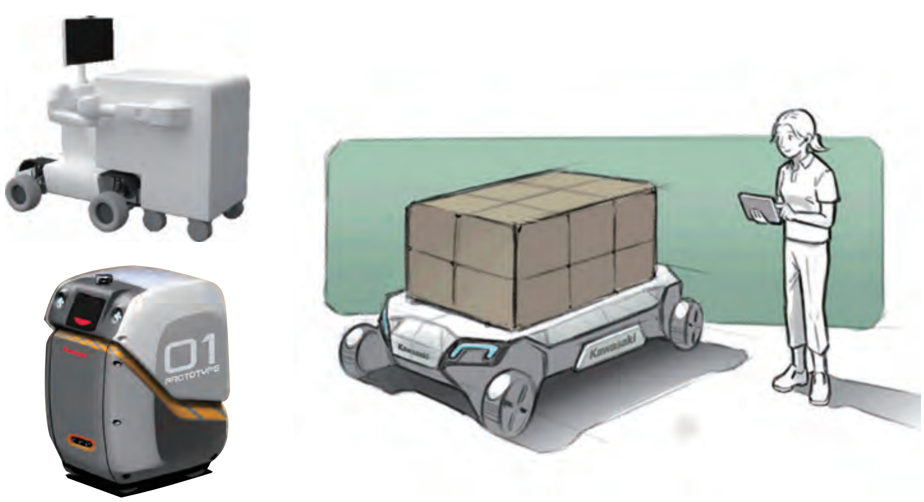


Fig. 2 Concept of a seamless logistics solution



(a) Delivery robot

(b) Multi-purpose UGV

Fig. 3 Delivery robot and multi-purpose UGV

Fig. 4 Demonstration test on a factory road of the first prototype on a factory road

As of June 2021, Kawasaki has conducted autonomous driving tests as a technological demonstration, with the first prototype (shown in **Fig. 4**) driving along the factory roads at its Akashi Works, and the company has obtained satisfactory results. Also, Kawasaki plans to conduct technological demonstrations on public roads with its partner companies in late 2021.

(2) Multi-purpose UGVs

Kawasaki is developing UGVs for logistics based on its technologies for off-road four-wheelers. These UGVs are differentiated by their high running-through performance, which is based on Kawasaki's off-road technologies, and in addition to somewhat uneven roads, the UGVs can also run on the rough roads seen, for example, at construction sites. The running-through performance can be adjusted according to the application. Looking ahead to decarbonization in the future, Kawasaki is also working to electrify these vehicles.

(3) Unmanned VTOL aircraft

Kawasaki has developed helicopter technologies and high-power small engine technologies for motorcycles. By combining these technologies, Kawasaki is developing unmanned VTOL aircraft with the aim of achieving a 200-kg payload, which cannot be achieved with common unmanned aircraft (e.g., drones). In the future, the VTOL aircraft will also be equipped with carbon-neutral power units.

The following describes the development of the unmanned VTOL aircraft.

3 Unmanned VTOL aircraft

(1) Development policy

Assuming transport in mountainous areas as the first target market, we will conduct technological demonstrations in a phased manner, aiming for the production models to transport a 200-kg payload at an altitude of 3,000 m.

First, we will develop transport demonstrator K-RACER-X1 by adding a 100 kg payload at sea level to the existing aircraft, and we will conduct a technological demonstration for the purpose of quickly incorporating customer feedback.

Next, we will develop K-RACER-X2, a model that can carry a 100-kg payload at an altitude of 3,000 m by applying technologies and know-how obtained from our existing models and K-RACER-X1, and we will conduct a technological demonstration of transport in mountainous areas.

After these technological demonstrations, based on the results, we will develop production models.

(2) Efforts made so far (existing models)

As Kawasaki's development project-based internal research, we started the development of prototype unmanned aircraft for research on compound helicopters in fiscal 2015 under a five-year scheme. The purpose of this research is to develop unmanned compound helicopters and to acquire the technologies required for both speeding-up and realizing unmanned operation through testing.

Typical examples of compound helicopters that have another propulsion force in addition to the main rotor are Airbus Helicopters' Eurocopter X^3 [2] and Sikorsky Aircraft's X2 [3]. Boeing Bell's tiltrotor [4] also has this configuration. In this research, we set the basic concept based on the configuration of Eurocopter X^3, which is the most similar to that of the conventional helicopters that Kawasaki has developed thus far, and then launched development.

For step-by-step development, based on the small electric unmanned helicopters on the market for industrial use, we first made the compound helicopter (main rotor diameter: approx. 2m) together with a flight control system for it, and we verified flight control laws developed by KHI for the compound helicopter. During this stage, we demonstrated that the compound helicopter could fly automatically through predetermined waypoints.

While developing the small compound helicopter, we designed and produced a large compound helicopter (main rotor diameter: approx. 4m). The large compound helicopter required high horsepower to fly at the target speed of 200 kt. No high-power engines for unmanned helicopters of this class were available; therefore, for this helicopter, we decided to use the engine mounted on Kawasaki's motorcycle Ninja H2R.

With the large compound helicopter K-RACER-IV, we conducted ground functional tests and ground resonance test at the ground test site of Kawasaki's Gifu Works between December 2018 and March 2019. In addition, as shown in **Fig. 5**, the first flight was made at the Gifu Works athletic field in April 2019. After solving the problems identified during the first flight, a second flight test was conducted at the Gifu Works athletic field in November and December 2019 in order to verify feasibility as an aircraft.

After that, as the final test under the five-year scheme, the flight test shown in **Fig. 6** was conducted at Taiki Multi-Purpose Aerospace Park in Hokkaido in July 2020 in order to demonstrate stable flight conforming to Kawasaki's compound helicopter flight control laws. Also, the automatic return flight to the take-off point was verified with a view to BVLOS (Beyond Visual Line Of Sight) automatic flight .

(3) Development of transport demonstrators

The aforementioned K-RACER-IV has been designed for high-speed flight; therefore, it has a light payload. For K-RACER-X1, the main rotor specifications were modified and the skid was expanded in order to enable carrying of a 100-kg payload with minimal modifications from K-RACER-IV.

To achieve the goal of seamless, unmanned/labor-saving logistics, it was decided to equip K-RACER-X1 with an automatic take-off and landing abilities. Also, since the

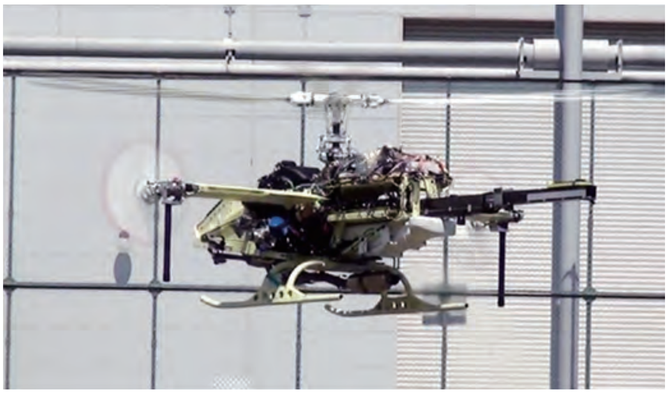


Fig. 5 First flight of K-RACER-IV (April 5, 2019)

Fig. 6 Flight test of K-RACER-IV at Taiki Multi-Purpose Aerospace Park (July 2020)

first target market for the production model is transport in mountainous areas, the function was added to fly automatically with external load operation With K-RACER-X1, we conducted an internal flight test and to verify the automatic flight sequence, including automatic take-off and landing, in autumn 2021. We will continue the development of automatic flight with external load and conduct an internal test in spring 2022.

Simultaneously with the development of K-RACER-X1, we are developing K-RACER-X2, which is intended for transport in mountainous areas. As for K-RACER-X2, we are in the basic design stage and making the most of the knowledge we acquired during the development of K-RACER-X1. We are designing the specifications of K-RACER-X2 with a view to mass production, and we will start prototype production of K-RACER-X2 in series. The development, including internal flight tests, is scheduled to be completed around September 2022.

(4) Demonstration tests

We plan to conduct demonstration tests to incorporate customer feedback into the production models and to demonstrate the usability and safety of unmanned VTOL aircraft.

(i) K-RACER-X1

For K-RACER-X1, we conducted demonstration tests mainly at low-altitude test sites, such as airfields or test airfields for unmanned aircraft, on transport with a 100-kg payload and on seamless, unmanned logistics with delivery robots as shown in **Fig. 7** (autumn 2021) and we plan to conduct automatic flight with external load (after spring 2022).

(ii) K-RACER-X2

For K-RACER-X2, we plan to conduct a demonstration in which a payload is transported to a mountain lodge in order to demonstrate transport in mountainous areas with a view to operation of the production model. Conducting these demonstration tests requires collaboration with local communities that provide test sites as well as collaboration with telecommunication companies and coordination with relevant ministries and agencies for unmanned BVLOS automatic flight. We are presently coordinating with the parties concerned. We plan to start demonstration tests after autumn 2022.

(5) Plan to bring the unmanned VTOL aircraft to market and challenges in commercial production

As the basic policy for commercialization, we plan to begin with transport in uninhabited areas (mountainous areas), which has certain market needs with a low safety risk on the ground, and then gradually expand the operation area. For the production model, customer requests and safety technologies obtained through the demonstration test in mountainous areas will be incorporated into the aircraft specifications, which are based on those of the K-RACER-X2. The production model will be categorized as a remotely piloted aircraft, and operation of such aircraft, like that of conventional manned aircraft, requires type certification and airworthiness certification. However, there are currently no specific design standards in place for remotely piloted aircraft (airworthiness classification and airworthiness examination procedure), and no remotely piloted aircraft have been granted type certification and put into service as unmanned transport aircraft so far.

Therefore, in order to put K-RACER into service for cargo transport as a production model, certification standards must be developed for remotely piloted aircraft before type certification. Certification standards for remotely piloted aircraft differ greatly from those for manned aircraft in that remotely piloted aircraft carry no crew and that remotely piloted aircraft can be operated remotely from the ground by an operator. With respect to these points, all requirements for the aircraft (and the

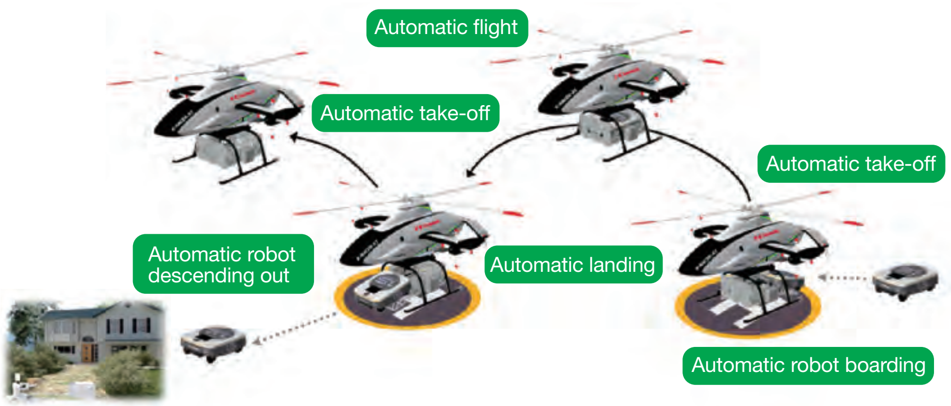


Fig. 7 Demonstration plan for seamless and unmanned logistics using K-RACER-X1 and delivery robots

entire system), including the communication method and flight traffic control, must be established in advance. We are now consulting with the Japan Civil Aviation Bureau to formulate certification standards.

Commercialization requires that aircraft development costs and product costs be minimized. Therefore, operation of unmanned aircraft in uninhabited areas (mountainous areas) must be appropriately assessed in terms of air and ground risks, and the required level of reliability and safety with adequate quality must be ensured while aiming to realize a reasonable aircraft without an excessive quality. To do so, it is important to formulate appropriate certification standards for individual applications (use cases) in order to realize new mobility.

Conclusion

Kawasaki will first bring its delivery robot and multi-purpose UGV to market as quickly as possible and offer a seamless ground logistics solution in combination with its palletizing and depalletizing robots. It will then bring an unmanned VTOL aircraft to market to offer seamless ground and air logistics, thereby contributing to solving the logistics challenges that society faces. In the future, Kawasaki will expand this business into passenger transportation services, bringing about innovation in passenger and cargo transportation by means of automation and remote control.

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