Developing a Flexible Production System: Transforming the Vehicle Production Process

The US market for off-road vehicles is projected to experience steady growth, and our Group Vision 2030 anticipates a sales increase of 20% to 50% for motorcycles and 40% to 60% for off-road vehicles. To implement this growth strategy and achieve our Group Vision, we are driving the reform of our production processes related to vehicle assembly. The aim of this transformation is to be flexible enough to adapt to customer demand while minimizing costs and maximizing productivity.

Introduction

The market environment around Kawasaki Motors is projected to experience steady growth due to the growth of the off-road four-wheel vehicle market in North America, a recent sales increase of supersport motorcycles, and other factors.

1 Background

To achieve our Group Vision 2030 and subsequent sustainable growth, we aim to develop into a company that surpasses competitors in the global market by continuing to promptly supply products to customers in order to ensure reliable income.

Essential to attaining this goal is developing a flexible production that can adapt to customer demand, while also reducing production costs at each production base and pursuing efficient production.

We believe that the role of the Akashi Works is to pioneer the promotion of DX as the true mother factory for each production base, and to lead other factories in developing production technologies and reforming production processes. Of the production processes at the Akashi Works, we selected the vehicle assembly, parts management, and parts transport processes, which are end-product production processes, as the initial targets, and started factory visualization that leverages digital technologies and enables us to reform production processes based on the visualization.

2 Challenges and action policies

The production processes related to vehicle assembly present the following challenges.

(1) Vehicle assembly line

The vehicle assembly process not only determines the final quality of products but also must flexibly deal with disturbances such as changes in market demand and issues related to parts supply. This is an important process in smoothly conducting all production activities, including those on the parts production line, which comprise casting, machining, welding, painting, and other steps. For the vehicle assembly process to play this important role, we must be able to quickly reorganize our production lines even in irregular circumstances to achieve the production plan.

Currently, each vehicle assembly line can only produce predetermined models. As a result, several months are required to implement a line shift for all manufacturing processes when items are produced in parallel with other lines to increase production or when problems occur on other lines. The same applies when shifting production to another line if one line has problems. This is partly because there is not enough room along the lineside space full of parts racks to put in parts racks for an additional model. Another reason is that rewiring work is required to add or reposition parts racks due to the part poka-yoke (fool-proofing) system installed for each part to prevent assembly errors.

To solve these problems, we are considering discontinuing the parts racks and poka-yoke system along the lineside by synchronizing the parts supply so that only those parts required at a given moment are supplied to the line as production progresses (**Fig. 1**).

(2) Parts management process

We must store parts currently kept along the lineside somewhere else so that only those parts required at a given moment are supplied to the line as production progresses. In addition, the globalization of our supply chain has increased the number of imported parts, which, in turn, has increased the frequency of carrying parts from third-party warehouses dedicated to imported parts into the Akashi Works. We have also experienced other incidents such as the suspension of just-in-time (JIT) supply due to contingencies at domestic part suppliers. Under these circumstances, we need a radical transformation of the parts management method to build the following:

- An environment to centrally manage domestically and internationally procured parts at the Akashi Works' parts warehouse
- An environment to only supply parts from the parts warehouse to the production line at the moment they are needed.

(3) Parts transport process

Turret trucks and bicycles are used to transport parts on the Akashi Works premises, and trucks are used between factories. In both cases, humans are involved in transport.

However, the recently shrinking workforce resulting from the falling birthrate and the aging population is making it increasingly difficult to secure enough people to do the work. This is likely to disrupt production activities in proportion to the number of processes that require human intervention.

Therefore, we must prioritize coming up with methods that do not need human resources for processes where added value is not created, such as carrying tasks.

3 Current progress

We are working to solve the problems in the production processes related to vehicle assembly as follows.

(1) Production-synchronized parts supply system

To supply parts in synchrony with the progress of the assembly line and discontinue the parts racks equipped with the parts poka-yoke system, we will develop an automated delivery system (ADS) that calculates which parts are needed and when as products move along he assembly line.

The ADS will be designed to obtain progress information about each product on the assembly line

Fig. 1 Lineside parts racks and the poka-yoke system

based on BOM information, which is necessary part information by model, and assembly order information by vehicle assembly line.

The ADS creates the following instructions as shown in **Fig. 2**.

- Instructions to the warehouse to pick parts in synchrony with the progress of production
- Instructions to transport picked parts to the lineside

These instructions are linked with each parts warehouse management and automatic parts transport function described later. In response to them, parts needed for each assembly section are prepared on a dolly to be supplied to the lineside at an appropriate time.

(2) Warehouse management

To establish a parts supply system as shown in **Fig. 2**, we will build a new parts warehouse at the Akashi Works and create an environment to manage every part in bulk.

For parts management at the warehouse, we will adopt a free location method with which storage locations change fluidly to efficiently manage several tens of thousands of parts in a limited space. Furthermore, we will introduce a warehouse management system (WMS) to manage all processes from parts warehousing through delivery in it. Regarding delivery instructions for parts, the above-mentioned ADS outputs parts picking instructions for each dolly cyclically in a timely fashion and links them to manage a series of processes.

We are also eying the use of an automated multistory warehouse that makes effective use of the vertical direction and considering its introduction, taking the cost versus the benefits into account, to reduce the size and workload of the parts warehouse.

(3) Automated parts transport system in the factory

We investigated transport vehicles and systems from each manufacturer commercially available in the market to automate parts transport, and found that systems suitable for the environment and use at the Akashi Works are limited and expensive. Therefore, we decided to develop an autonomous mobile robot (AMR) in house that employs autonomous traveling technology. This is a state-of-the-art technology in the logistics industry.

(i) Autonomous traveling technology

Figure 3 shows the appearance of the in-house AMR and **Table 1** lists its specifications. The autonomous traveling mechanism employs the simultaneous localization and mapping (SLAM) method. With this method, the AMR travels, collating distance data positioned using its LiDARs against environmental data prepared in advance to estimate self-location. Moreover, this method is combined with the odometry technology to feed back the travel distance of the AMR calculated from the number of wheel rotations, and for advanced self-location estimation the nine-axis IMU sensor is used to correct the traveling posture and minute slips.

(ii) Flexible travel route setting

All AMR settings, such as travel routes, stop points, and travel rules, are configured in software. **Figure 4** shows map data and travel routes created on a vehicle assembly line. The motor, as well as the front and rear wheels and related components, are combined into the

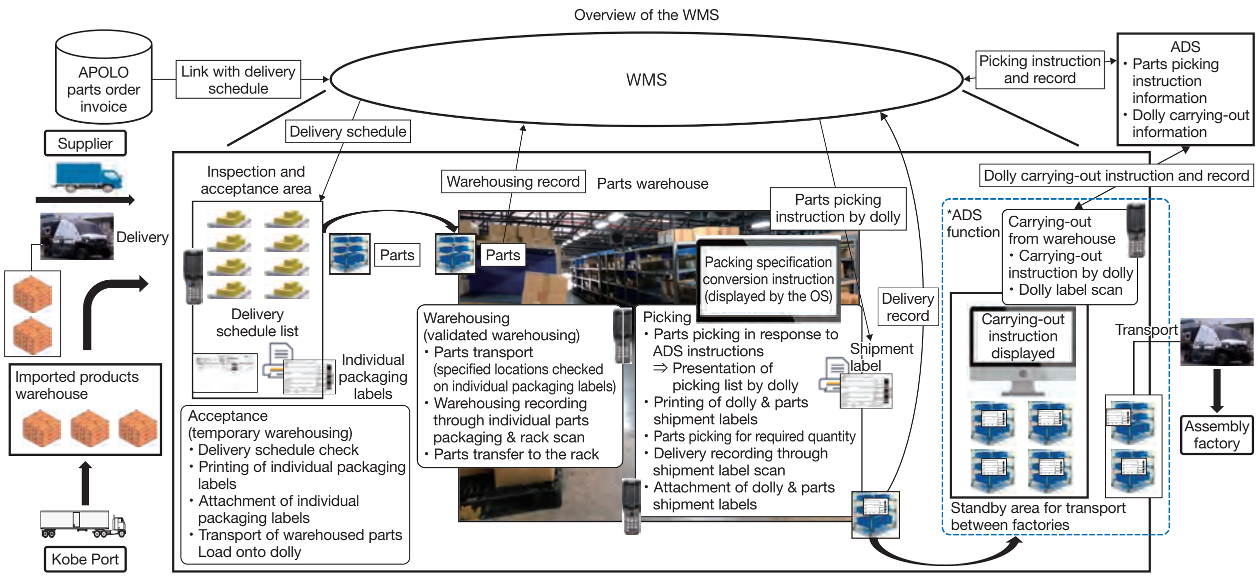

Fig. 2 Overview of the WMS and its peripheral systems

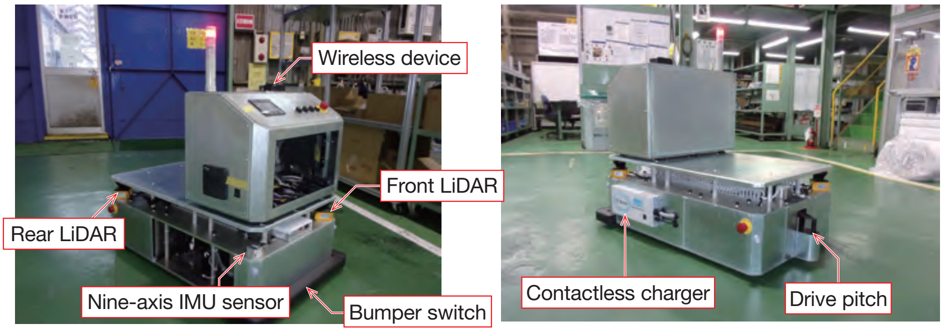

Fig. 3 Appearance of the AMR developed in-house

Table 1 Specifications of the AMR

Vehicle size [mm]		D1, 200×W750×H1, 130
Weight [kg]		200
Drive system		Differential two-wheel drive
Rated speed [km/h]		4. 7
Drive weight [kg]		300
Stopping accuracy	Distance [±mm]	10
	Angle [±°]	1
Battery capacity [Ah]		23
Charging method		Contactless quick charging
Charging current [A]		30

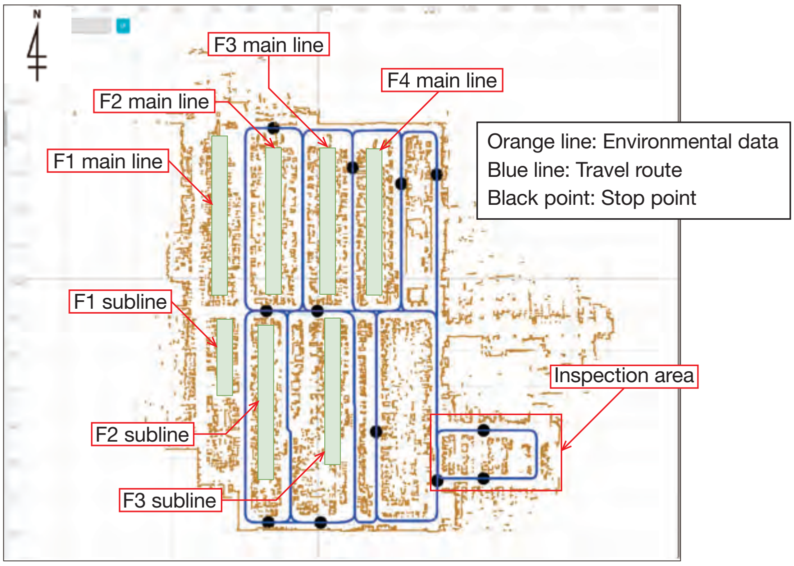

Fig. 4 Map data and travel route

frame on the sublines in the figure. These sublines are connected to the main lines across passages. On the main lines, peripheral components are assembled onto the body to finish the vehicle. First, the AMR is manually operated to obtain wall and column information as 2D point-cloud data. The obtained information is then edited to create map data. Afterward, travel routes, stop points, and other details are set. Because you can also divide and create map data, the map for even a vast area is easy to create and edit. Likewise, you can flexibly and immediately address changes in the internal layout, travel routes, and stop locations.

(iii) Coexistence with people and goods

When traveling toward people or goods, the AMR can avoid these obstacles without requiring guides installed on the floor. The AGV, whose travel route is determined, must stop if there are obstacles. In contrast, the AMR we developed here can avoid obstacles while traveling. This function is indispensable for delivering parts when needed.

(iv) Link with the host system

We developed a group control system for the AMR to link multiple AMRs with the ADS. The group control system properly allocates each AMR and gives transport instructions based on information from the ADS. The group control management screen can be used to monitor the travel positions, device status, and transport status of each AMR, obtain logs in case of problems, and provide feedback such as transport records.

(v) Safety function

The developed AMR has its safety function standardized according to JIS D 6802[1], the Japanese standard for the safety of unmanned transport systems. A safety system controller is prepared in a system separate from the travel controller and PLC to configure a circuit that immediately stops travel if the safety system is activated. The system consists of an emergency stop button, a bumper switch to detect collisions by the AMR, a laser scanner that creates a protected area around the AMR, as well as a virtual bumper that varies its area depending on the speed, curves, and other conditions. Safety certification has been obtained for all of these devices.

(4) Automated inter-factory parts transport system

Parts picked in a parts warehouse in response to ADS instructions are automatically transported between factories using the multi-use unmanned ground vehicle (MUGV) (**Fig. 5**).

Fig. 5 Appearance of the MUGV

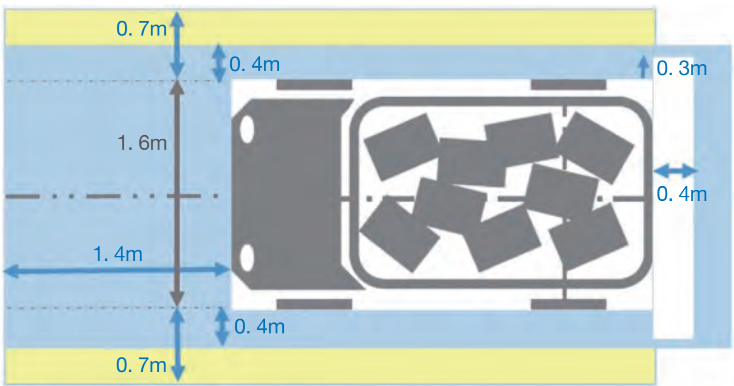

Fig. 6 Surrounding detection range

The MUGV is an automated parts transport vehicle used between factories (outdoors). This vehicle can also be operated by a driver. Autonomous operation requires the travel controller to automatically control speed, steering, and other factors in response to manual input of operations from the steering wheel, accelerator, brakes, or other device, and the autonomous controller to identify the current vehicle position and surrounding obstacles from data obtained with LiDAR sensors and control autonomous travel on determined travel routes. We prioritize safety during operation by requesting risk assessment from an insurance company, considering autonomous control specifications, and incorporating a safety system, particularly when developing the autonomous controller, so that unmanned vehicles can safely travel in factories where pedestrians, bicycles, trucks, and other delivery vehicles move back and forth in a complex manner. Although its autonomous travel method is basically the same as the AMR's, the MUGV conducts more advanced self-location estimation and environment identification using 3D LiDAR sensors and map data to which information on speed limits, crossings, intersections and other elements is added.

The autonomous controller software is Autoware, an open-source autonomous traveling OS. We repeatedly verified its operation and implemented the following functions to address obstacles during travel.

① Function to detect obstacles in front of the vehicle and follow them or stop

The MUGV can slow down and stop 5 m in front of obstacles. If obstacles move, the vehicle can follow them, maintaining a distance of at least 4 m.

② Function to detect obstacles to the right or left of or behind the vehicle

The MUGV can also detect obstacles around it and slow down or stop, as shown in **Fig. 6.** (The MUGV slows down in the yellow areas and stops in the blue area.)

③ Operation with moving object prediction

The MUGV can predict the movement of moving objects at crossings and intersections using AI, and decide whether to continue operation, slow down, stop, or perform other operations based on the prediction.

Conclusion

We will contribute to implementing the growth strategy in our Group Vision 2030 by refining vehicle assembly production processes at actual production sites. We will also lead other bases as the true mother factory and pursue lower production costs and higher production efficiency for the whole group to secure reliable profits and help the company surpasses competitors in the global market.

References

1) JIS D 6802:2022 Automatic guided vehicles and systems – Safety requirements and verification

Kazunobu Morota
Production Engineering Department,
Manufacturing Division,
Kawasaki Motors, Ltd.

Taku Murakami
Production Engineering Department,
Manufacturing Division,
Kawasaki Motors, Ltd.

Yoshihiko Tasaka
Global Production Management Department,
Manufacturing Division,
Kawasaki Motors, Ltd.

Takato Nishio
Production Engineering Department,
Manufacturing Division,
Kawasaki Motors, Ltd.

Kouhei Tsuruta
Global Production Management Department,
Manufacturing Division,
Kawasaki Motors, Ltd.

Taiki Okada
Digital Process Department,
Digital Strategy Group,
DX Strategy Division