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# Human–Robot Hybrid Service System Introduction for Enhancing Labor and Robot Productivity

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**Abstract.** This study introduces service robots to improve restaurant industry labor productivity because restaurant productivity is the lowest among service industries. Furthermore, this study represents an attempt to improve robot productivity because low robot productivity is the main hindrance to robot introduction into service industries. Service robot systems developed based on AGV robot systems were incorporated into operations of an actual restaurant. Staff operations changed. The AGV replaced conveyance operations to reduce staff work loads. Moreover, the AGV systems are refined to increase AGV work loads: the number of AGV battery chargers was increased to avoid electric battery power shortages, AGV boards were changed from fixed type to removable type. Moving patterns increased from 1 to 4 to adopt AGV operation for restaurant operation situation changes. Results indicate that the system redesign improves labor productivity. It reduces working time and increases service quality. Furthermore, the AGV system refinement enhances robot productivity: in fact, the total AGV daily moving distance was doubled.

**Keywords:** Productivity, Restaurant, Service engineering, Service robot

## 1 Introduction

Generally speaking, service industry productivity is low, even though service industries represent key industries, accounting for around 75% of Japanese GDP. “The growth of service economy” trend is not only true for Japan, but also for all industrialized countries such as the US, the UK, France, and Germany. Enhancing service industry productivity is an important strategy for these countries and service companies worldwide. Moreover, restaurant industry productivity is the lowest among service industries. The cause of low productivity is so-called “labor intensive” production systems. The industry must evolve a human-based production system to achieve a productivity breakthrough.

In the 1950s, the US restaurant industry introduced chain store operation systems to enhance industry productivity [1]. Chain store operation systems have adopted central kitchens, similar to food factories, to reduce the total number of cooking staff at

restaurants. Furthermore, systems have introduced multi-restaurant strategies to realize volume economies. The restaurant industry has even reduced ingredient costs through bulk buying. The system simplifies menu and service operations to reduce staff skill dependence. A simplification strategy is intended to reduce average labor costs. In the 1970s, the Japanese restaurant industry introduced operation systems. Consequently, the industry has become a key industry in Japan.

In the 1980s, the restaurant industry introduced point of sales (POS) systems to improve restaurant operations [2]. Before POS introduction, restaurants recorded order information using paper checks: when a service staff member receives an order, the staff member writes it down on the order sheet, walks from dining room to the kitchen, and hands it to the cooking staff. Several minutes are necessary for order information transmission. Furthermore, a paper is sometimes lost. In such cases, service staff members must stroll around the restaurant to find the customer who ordered a certain dish. By contrast, POS systems automatically transmit order information via a wireless communication network. For that reason, service staff need not enter the kitchen. Also, POS systems record the order information in a POS terminal. A sheet can be reprinted if a service staff member loses it [3].

In the 1990s, the restaurant industry introduced new cooking equipment to realize cooking automation. For instance, the industry introduced convection ovens for automated steaming, baking, and boiling [4]. Also, the industry combines plural cooking equipment and machines to realize automation-based kitchen systems. A typical example is so-called “Kaiten sushi” (conveyer sushi). The purpose of machine introduction and kitchen systems is maximization of production capacity and reduction of the total number of cooking staff [5]. In addition, the industry has launched some studies for kitchen operation system enhancement. For instance, the cooking capacity of individual cooking machines is measured and compared with the volume of customer orders of individual cooking machines to find a bottleneck. Based on that comparison, the number of cooking machines or menu varieties might be redesigned to optimize supply (cooking capacity) and demand (customer order) [6]. In addition, a new cooking system, a line and cell production combination system, is introduced into an actual restaurant to improve productivity. The results of the study indicate it as useful for productivity enhancement [7].

Early in this century, AI and simulation technologies were developed for use in industry. For instance, kitchen simulation systems were developed based on a factory simulation system, and were introduced for actual restaurant redesign [8]. In addition, simulation systems for central kitchens were introduced into restaurants [9].

Although conventional studies continuously resolve low-productivity problems, some difficulties remain. The first difficulty is how to overcome “service product characteristics [10]. Actually services have special characteristics. By and large they are intangible, indicating their fundamental Intangibility. Therefore, services can not be stocked. They are therefore known for their Perishability. Consequently, service products should be produced simultaneously with a customer order. Services therefore have Simultaneity. For instance, service staff should take order at the same time a customer order it, and they should serve dishes at the same time chef finish the order cooking. If conveyance operation are replaced from human to robot, productivity of service staff

will be enhanced. A second problem is that production systems evolve. Conventional studies and methods mainly address individual production modes such as humans, machines, or IoT. For instance, convection oven machine is stand-alone system for simmered food; it is not much more than tool for cooking staff. Point-of-sales system is order information and account control system for restaurant; staff and the system do not make cooperation. Restaurant service systems should combined all three factors synergistically, as human, machine, and IoT hybrid systems. As society 5.0 proposes, service industries should mix these technologies and combine them with human-based service systems [11]. A third problem is robot productivity itself. At present, service robot productivity is markedly low, compared to that of factory robots. The reason is simple: actual service sites are not accommodative of robots. For instance, service staff members have only insufficient experience operating robots, controlling robots. Service staff stop using robot and work themselves if restaurant become busy, because it is quicker and robot operation is messy. In addition, service robot operation speed is kept low to avoid accidental contact between humans and robots. Different from factory robots, service robots, and staff work together. Therefore, robot speed should be controlled slow. To enhance service productivity, robot productivity must be enhanced along with labor productivity.

This study developed a human–robot hybrid service system for restaurants and introduced it into an actual Japanese cuisine restaurant store to enhance labor productivity and robot productivity.

## **2 Human–Robot Hybrid Service System for Restaurant**

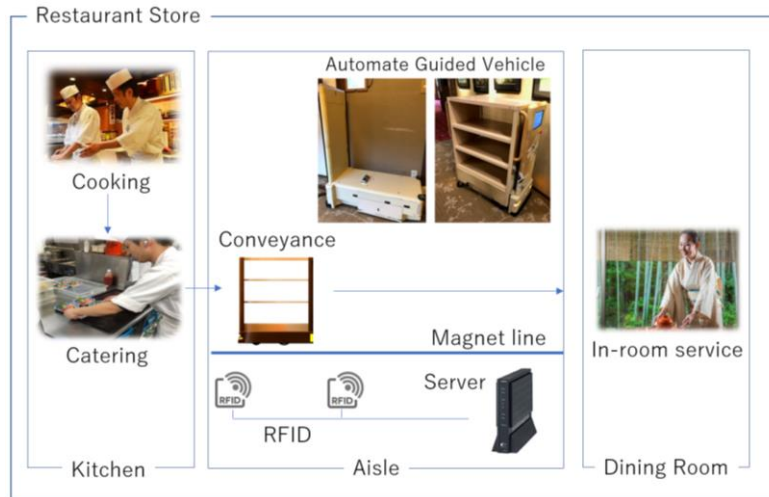
### **2.1 System structure**

Traditionally, traditional restaurants are operated by skillful staff because human-based service systems provide core value for customers. Kitchen staff cook dishes, the catering staff check food quality, add garnish, and top sauces. Subsequently, the conveyance staff move the dishes from the kitchen to a dining room before service staff members serve it to customers. Catering staff support the conveyance staff in resolving delays because long waiting times lead to customer dissatisfaction if a dish can not be moved from the kitchen to a dining room because of high workloads.

Restaurant value for customers is fundamentally created by kitchen staff members because the purpose of dining out is to be entertained with fine foods. Furthermore, customers are entertained by in-floor service because customers enjoy interaction with service staff members, as well as eating foods. However, conveyance operations are also important for restaurant operations because they are indispensable processes with cooking and service. Nevertheless, the process does not create value for customers. Consequently, conveyance processes can replace humans with robots.

Figure 1 presents the hybrid service system structure for the restaurant industry. Cooking and service processes are done by humans. Conveyance processes are operated by service robots. The service robot system comprises four automated guided vehicles (AGV), 1 AGV control server, an AGV operation program, 50 RFID devices for

operation control transmissions, 9 tablets for AGV operation by staff members, 1 non-contact battery charger, 2 contact battery chargers, and a magnet guide line.



**Fig. 1.** System structures.

## 2.2 System introduction

The robot system was introduced for use in a Japanese traditional cuisine restaurant (1,648.2 m<sup>2</sup>, 441 sheets, and 1 kitchen). Before system introduction, robot operation training was conducted for restaurant staff. Thereafter, staff members had some discussions about “how to change the restaurant operation.” The restaurant then undertook service robot system introduction. Service operations were changed based on the system hypothesis. The cooking staff cooks dishes. Then the dishes are loaded on AGV by catering staff. The staff destination of the AGV is designated by referring to the order information. The AGV automatically moves from the kitchen to the dining site. A service staff picks up the delivery and takes it to the customer.

Service staff members sometimes discuss operation improvements intended for enhancing labor productivity. Each staff member changes work scheduling. A conveyance staff shifts from conveyance operations to in-room service operations so that service staff can concentrate on dish serving and conversations with customers. In addition, catering staff members shift from conveyance to cooking for enhancing dish quality and reducing lead times. Based on operation changes, the store manager changes the shift roster to reduce the restaurant store working times.

Sales per work hour are measured as a KIP for enhancing labor productivity. Daily sales are calculated by the POS system. Actually, the system records individual orders. From them, it calculates daily sales by summing up unit prices. Daily work hours are measured by an attendant management system. When a staff member starts working, the staff member inputs the employee ID and pushes a “start working” button. Then the system records the clock time. When the staff member finishes working, the system records the clock time when the “finish working” button is pushed. Sales per work hour

are calculated as the sales revenues divided by work hours. The measurement is conducted for 9 weeks from 2 months after AGV system introduction because the operation efficiency worsens immediately after the system introduction. Typically, staff members are not accustomed to using system operations. Sales per work hour are compared to those of the same week the prior year because sales differ from season to season.

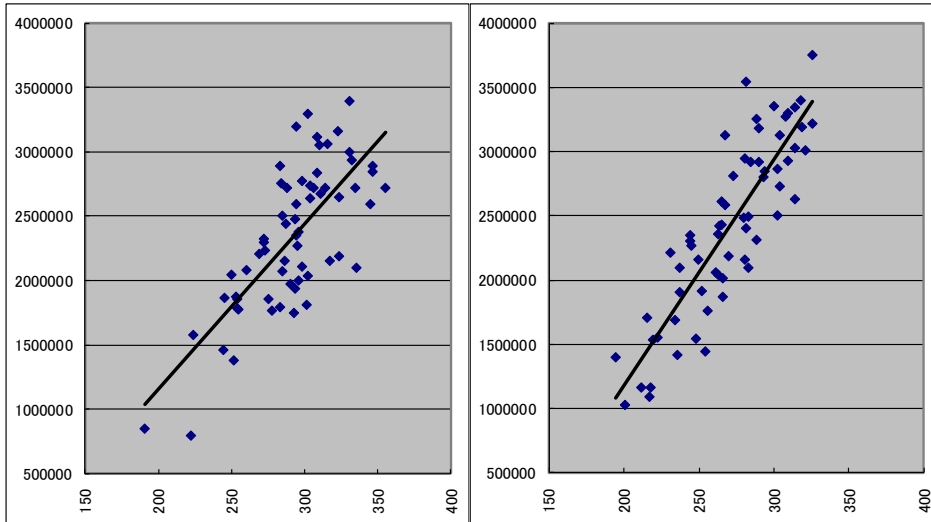
At two months after the system introduction, the store manager, head chef, service manager, system designer, and store designer hold meetings to improve AGV productivity. Based on their discussions, the system was actually redesigned several times. First, the AGV base board was redesigned from a fixed type to a retractable type because dishes put on an AGV and stopped in an area lead to AGV immobility. It can not be moved because the dishes should be served to the nearby customer. Staff members need only retract the board to operate an AGV if an AGV base board is retractable. Second, contactless battery chargers were increased from 1 to 2. Also, the contact chargers were increased from 2 to 4 to avoid shortcomings caused by weak batteries. Different from factory robots, service robots are operated without a power supply cable. Therefore, they sometimes stop if a battery is low. Battery charge methods and timing are important factors for AGV operation. Furthermore, basic operation patterns were changed from 1 to 4 because operation situations differ from time to time: open preparation times, rush times (lunch / dinner), setup times (idle time), and closure operations.

One year after AGV introduction, the average AGV running distance per day per customer was compared as a KPI for robot productivity, because if AGV convey many foods, its moving distance gets long. The daily individual AGV running distance was recorded by an AGV server. The average running distance was calculated as the daily total running distance divided into the working AGV number. In addition, the total numbers of customers the respective days were recorded by the POS system and were downloaded from the POS server. The average AGV running distance was compared with the same week during the prior year because sales differ from season to season.

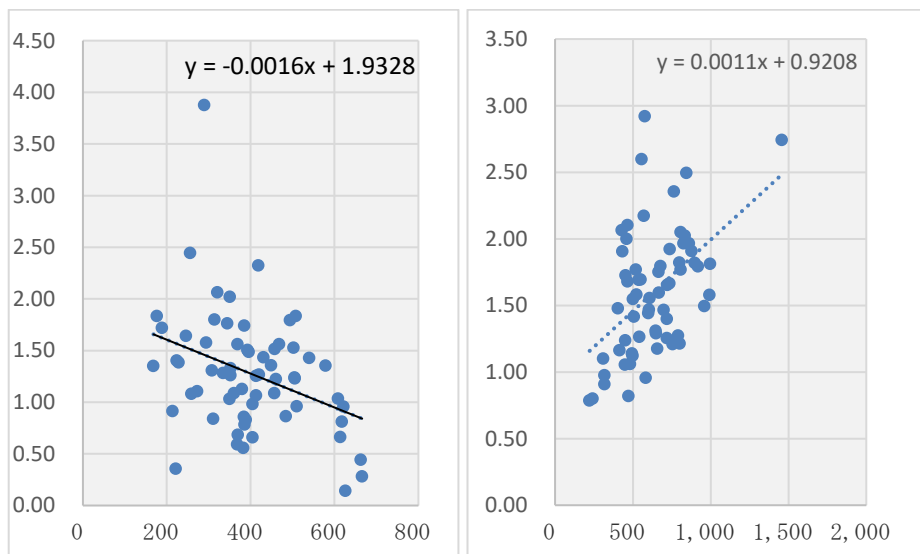
### **3 Results and Discussion**

#### **3.1 Results**

Average daily sales of conventional service ecosystem (prior year) were 2,237,302 yen (SD=559,053). Daily service staff work hours were 292.2 hr (SD=32.4 hr). Average sales per work hour were 8,000 yen. The coefficient of correlation was 0.74. Average daily sales of the redesigned service ecosystem (prior year) was 2,416,935 yen (SD=682,249). Daily service staff work hours were 270.6 hr (SD=33.7 hr). Therefore, the average sales per work hour were 8,932 yen. The coefficient of correlation was 0.87. Figure 2 (left) presents work hours and sales point diagrams for the prior year. Figure 2 (right) shows those of the present year. Assuming equal variance with one-sample  $t$  tests, we found a significant difference in the means ( $t(63)=5.382, p<0.05$ )



**Fig. 2.** Work hours and daily sales point diagram:  
horizontal axis, work hour (hour); vertical line, daily sales (1,000 Yen).



**Fig. 3.** Robot moving distance and a number customer point diagram:  
horizontal axis, daily customers (person); vertical line, AGV moving distance per customer (meter).

The average moving distance per customer of the first year was 1.27 m (SD=0.58 m). The average total distance of 1 AGV was 511 m. The coefficient of correlation was 0.12. Also, the average moving distance per customer of the second year was 1.60 m (SD=0.47 m). The average total distance of an AGV was 1,012 m. The coefficient of correlation was 0.24. Assuming equal variance with one-sample  $t$  tests, we found a significant difference in the means ( $t(124)=3.434$ ,  $p<0.01$ ).

### 3.2 Discussion

First, labor productivity improvement can be discussed based on sales per work hour. The main purpose of AGV system introduction was to replace conveyance operations conducted by humans with work done by AGV robots. Mainly, AGV systems take over the tasks of conveyance staff members. Thereby, conveyance staff members reduce their workload. In addition, catering staff reduce the frequency for conveyance because they need only to put dishes on the AGV. Therefore, they need not convey them by themselves. Based on the operation changes, the store manager reduces the total daily working time. Results show that work hours of the restaurant are reduced compared to those before AGV introduction. Results demonstrated that AGV introduction did not reduce service quality because daily sales were not reduced by AGV introduction. Instead, daily sales increased from 2,237K to 2,416K yen. Therefore, the system might enhance service quality. As explained earlier, the conveyance staff shifted their tasks from conveyance to in-room service support. Therefore, service staff can concentrate on customer service. Also, service staff need not pick up dishes at the kitchen because the AGV automatically convey them. Service staff get good feedback about service quality from customer. Catering staff shifted their tasks from conveyance to cooking. Therefore, dish quality improved because the total work hours at the kitchen were increased. Cooking staff evaluate food layout is improved by catering staff rework. Productivity comprises two factors: reduced labor input and increased added value. The restaurant system redesign realized both.

Secondly, robot productivity improvement is discussed based on results data. As results indicate, the AGV moving distance per customer increased 126.0% (1.27 m→1.60 m); the daily total AGV moving distance increased 198.0% (511 m→1,012 m). Results show that AGVs saved some time. That time is represented by increased AGV moving distance. Also, staff abilities for AGV operation improved because they became accustomed with AGV operations. Their efforts increased the AGV workload. They used AGVs because they have sufficient leeway for AGV operations if the restaurant is idle. However, if the restaurant is busy, they have insufficient leeway. Then they conveyed dishes by themselves because they became accustomed to it. As Figure 3 (left) shows, the AGV moving distance increased when the restaurant was idle, but it decreased as the restaurant become busy (approximate line have a negative slope in proportion as sales increase). However, proficiency for AGV operations changes the situation. They use AGVs continuously for conveyance if the restaurant is idle. They use AGV systems for conveyance because they have sufficient leeway for AGV operation if the restaurant becomes busy. As a result, the average AGV moving distance for one customer increases if the restaurant becomes busy (Figure 3 (right)).

## 4 Conclusions

For this study, service robot system is introduced in an actual Japanese cuisine restaurant to enhance productivity. Staff members changed their operations. Conveyance staff replaced human operations with those of AGV robots. Catering staff also replace the operation to reduce workloads. In addition, the conveyance staff supports the in-



room service staff to improve service quality. Catering staff support cooking staff to enhance food quality. Based on operation changes, the store manager reduced the total working time. In addition, the AGV system was refined. The number of AGV battery chargers was increased to avoid electric battery power shortages. Also, the AGV board was changed from a fixed type to a removable type. The moving patterns were increased from 1 to 4 to adapt AGV operations to changes in the restaurant operation situation. Results indicate that the system redesign improved labor productivity: it reduced working time and also increased service quality. The AGV system refinement definitely enhanced robot productivity: the total AGV daily moving distance was doubled.

## Acknowledgments

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