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Divide and conquer: A hygienic, efficient, and reliable assembly-line for housekeeping

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Divide and Conquer: A Hygienic, Efficient, and Reliable Assembly Line for Housekeeping

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Abstract:

Problem definition**:** This work focuses on the hotel housekeeping process. In a field study, a possible channel of disease transmission between consecutive guests in hotel rooms is revealed. In order to prevent the transmission, an innovative assembly-line housekeeping method is developed. ***Academic/practical relevance*****:** The transmission of infectious diseases during hotel stays (e.g., by touching unclean towels or bed linens) has been reported globally. Under the current COVID-19 pandemic, having contact with saliva or mucus left by an infected person could cause infection. The standard housekeeping process used by the majority of hotels leaves a channel for new towels and bed linens in refreshed rooms to be contaminated by bacteria or viruses from used towels and bed linens. Eliminating the contamination channel and preventing disease transmission are crucial for protecting the health and safety of hotel guests, especially under a disease outbreak such as the current COVID-19 pandemic. ***Methodology*****:** The research was conducted during a field study at a hotel. To design the assembly-line process, the service time distribution of each housekeeping operational step is characterized using data collected from the practice at hundreds of hotel rooms. An optimization model is proposed to optimize the operation. Through a pilot test, the performance of the assembly-line and the traditional housekeeping methods is compared. ***Results*****:** The pilot test results show that the assembly-line housekeeping method has the potential to improve not only hygienic standards but also, labor efficiency and service quality (error rate). ***Managerial implications*****:** The outbreak of the COVID-19 pandemic draws tremendous public attention on disease transmission and public hygiene. The principle of the assembly-line method (i.e., eliminating contamination channels through teamwork operational design) can be applied to not only hotel housekeeping practices but also, many other service settings. It leads to hygienic, efficient, and reliable operations, at no additional cost.

Keywords: housekeeping operation, assembly-line, hotel hygiene, labor efficiency

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1. Introduction

The outbreak of the COVID-19 pandemic draws tremendous public attention on disease transmission and public hygiene. According to the most up-to-date version of World Health Organization (WHO) and Centers for Disease Control and Prevention (CDC) guidelines, the primary transmission mode for COVID-19 is through respiratory droplets and contact routes (see Centers for Disease Control and Prevention 2020, World Health Organization 2020). From Ong et al. (2020), transmission of this novel coronavirus may occur through fomites in the environment around an infected person. Therefore, having contact with surfaces of objects touched or contaminated by an infected person may dramatically increase one's likelihood of infection.

According to Van Beusekom (2020), researchers have detected the virus in guest rooms of a quarantine hotel hours after the checkout of infected persons. Places containing the virus include surfaces of hotel room items (e.g., light switches and faucets), as well as towels, bedsheets, pillows, and duvet covers. From Nazario (2020), the virus can live for hours to days on surfaces. These facts severely worry travelers all over the world. Hotels, with the special features that the same room hosts different guests consecutively and that room items such as towels and bed linens directly touch the bare skin of guests, naturally cause public health concerns. Over the recent years, we have seen an increasing number of news and articles globally reporting hygiene issues related to hotel room stays. Public health authorities find high loads of bacteria on hotel bed linens during inspections. Guests catch infectious diseases after using towels in hotel rooms. (See the discussion on hotel hygiene issues in Section 2.1 for details.)

It is generally believed that the bacterial contamination is because of certain misconducts in housekeeping and laundry processes. For example, used towels and bed linens may not go through sterilization before being put into a new room; laundry facilities in the basement are often damp and uncleaned; bed linens that look clean in a checked-out room may not be changed; or used towels could even be casually washed and dried just inside guest room sinks.

With the development of hospitality executive training programs, hotel management experts started to publish protocols and sample videos on housekeeping and laundry practices. Nowadays, the majority of medium-end and high-end hotels around the world follow a version of the well-known six-step housekeeping procedure. (See the discussion on hotel housekeeping protocols in Section 2.2 for details.) However, despite the efforts on housekeeping and laundry standardization, outbreaks of hygiene-related problems remain at quite a high volume, even at luxury hotels.

In 2018, a high-end hotel (we call it JH in this paper) in a major city in China invited us to conduct a project with the aim to improve the service quality and labor efficiency of their housekeeping operations. JH always puts a high priority on and has extremely strict standards for public hygiene. For example, it owns a modern laundry and sterilization house, which is fully cleaned every day. All room attendants are full-time employees who hold periodically renewed health certificates. A daily housekeeping briefing session is held on every morning where compliments and complaints received on the previous day are released and discussed. Most importantly, to prevent reusing and not changing used towels at checked-out rooms, clean towels after sterilization are placed inside individually sealed bags. Hotel guests unpack the towels themselves at the time of usage. This is a very unique practice and receives great praise.

Although JH stays on the top of various hotel hygienic standards rankings cross the province, plausible disease transmission cases related to the usage of hotel room towels still happen. It seriously draws our attention. Towels after washing and sterilization never fail bacterial inspections, and they are placed inside individually sealed bags. Then, how could they be contaminated? After cleaning, room attendants disinfect the entire bathroom including the area where they place the sealed towel bags. Then, how could diseases from old guests or used towels exist inside the refreshed bathroom? Is there an ignored channel of contamination?

To find the answer, we closely watched the entire housekeeping practices performed by multiple room attendants. Although all of them perfectly followed the standard protocol (i.e., JH's version of the global six-step housekeeping procedure), we discovered an operation step that could cause the contamination. Briefly, after the attendant finished the cleaning of bathroom, he or she carried the whole set of used towels to the hamper truck outside the room and then immediately brought back a new set of towels from the housekeeping cart. Because towels are long, heavy, and perhaps wet, the attendant held them with his or her hands, arms, and chest. Thus, the contaminated hands (or gloves) and clothes touched the new set of towel bags. The same thing happened for the bed linens. In summary, the hands and clothes of room attendants could have created the transmission channel for infectious diseases.

We reported this finding to many hotel industry colleagues across different countries. It turns out that quite a few hotels, including major global brand ones, have noticed such an issue. Some hotels have even confirmed high bacterial loads on the gloves and clothes of their room attendants during hygiene inspections. For the prevention measures, there are hotels that require attendants to fully wash their hands before making beds and replacing towels, and there are also hotels that ask attendants to wear different gloves and aprons while conducting different operation steps. However, these actions are quite time consuming and tedious, and thus, attendants hardly implement them without supervision. To the best of our knowledge, there are no existing effective methods in real practice to prevent the mentioned attendant-caused towel and bed linen contamination. (To avoid unnecessary praise or blame for certain brands, we do not cite articles on the housekeeping protocols of particular hotels. However, descriptions and sample videos are widely available online.)

To solve this problem, we designed an innovative housekeeping process. We call it the *assembly-line* method. Basically, we separate all the operational steps of a housekeeping job into two parts, *contaminated task (task C)* and *sanitary task (task S)*. Task C includes steps such as removing old linens and cleaning bathrooms, and task S includes steps such as making beds and replenishing towels. Most importantly, instead of letting one attendant conduct the entire housekeeping job of a room himself or herself as the majority of hotels now do, we make two attendants form a team and complete the two tasks in sequence. For each room to be cleaned, *attendant C* only conducts task C, and *attendant S* only conducts task S. The two attendants move into the rooms in sequence. For example, when attendant C is performing task C in Room 2, attendant S is performing task S in Room 1. After a while, when attendant C completes task C in Room 2 and moves to Room 3, attendant S enters Room 2 to perform task S; on and so forth.

The fundamental principle of our assembly-line method is to make sure that contaminated hands and cloths never touch new towels and bed linens. After attendant C disinfects the room, the room is bacteria free. Because the new towels and linens only touch clean hands and surfaces, they would not be contaminated. We acknowledge that there exist certain bacteria or viruses that cannot be disinfected or killed by normal disinfectants or detergents. Hotels have to choose correct antiseptic products based on their own circumstances. The CDC of many countries and territories have their recommendations on this, especially during tourism peak seasons or under pandemics. This paper only deals with the process design of housekeeping practice and focuses on disease transmission caused by operational misconducts. We do not discuss the details of particular diseases or viruses but refer interested readers to epidemiology and public health professional articles. We also remark that it is almost impossible to achieve perfectly hygienic conditions and guarantee bacteria free at every corner of a hotel room. However, the hygiene condition of towels and bed linens is generally of the greatest concern. Our innovative assembly-line process design only aims to eliminate the crosscontamination caused by the contact of new towels with bacteria on attendants' hands and clothes. How well attendants perform every single operational step and maintain the sanitary condition of their equipment are still crucial to ensure the hygienic standards.

When we take a closer look at our assembly-line method, it works well under the condition that the two attendants complete their tasks at a similar speed, so that the time point that attendant C finishes task C in Room 2 is very close to the time point that attendant S finishes task S in Room 1. In this way, the two attendants move among the rooms synchronously. We can imagine that, if the completion time of task C is much longer than that of task S, then attendant S will waste time to wait before entering rooms. In contrast, if the completion time of task S is much longer than that of task C, then attendant S will be far behind, which creates many work in progress rooms not available for guests. Thus, it is important to have an *even allocation of workload*. In other words, we should make the expected completion times of task C and that of task S close to each other.

For the workload allocation, there are operational steps that must be included in task C or task S. For example, removing old bed linens has to belong to task C, and making beds has to belong to task S. We cannot put removing linens (making beds) into task S (task C), as it breaks the fundamental principle of the assembly-line method. However, the allocation of certain operational steps is optional. For example, vacuuming can be performed by either attendant, as long as the attendants stick to plan for all rooms. The same follows for air freshening and some other steps. To make an even allocation, we have to understand the service time of each individual housekeeping step. In the field study at JH, we collected data from the housekeeping practice at hundreds of rooms and characterized the service time distribution of every single operational step. We then built an optimization model to find the best allocation plan.

It is worth mentioning that our assembly-line method was rejected by some hotel practitioners at first glance because they thought the method requires doubling the manpower. This intuition is wrong because the total workload of all rooms in the hotel stays the same. In fact, our pilot test results showed that the *assembly-line method has the potential to improve not only hygienic standards but also, labor efficiency*. It is not difficult to explain such a phenomenon. First, under the assembly-line method, attendants do not need to commute between guest room and housekeeping cart as many times as they do under the traditional method. More importantly, under the traditional method, an attendant needs to repeatedly switch among six different operational steps, whereas under the assembly-line method, one only needs to switch among no more than four steps. When workers are focused on fewer tasks, they work faster.

Another great benefit of making attendants focused on fewer tasks is the remarkable drop in housekeeping service error rate. Errors in housekeeping service refer to the imperfect conditions in refreshed guest rooms because of the carelessness of room attendants during housekeeping operations. Typical errors include leftover trash, uncleaned drawers, incorrect count of towels, missing bottled water (in hotels offering complimentary water for guests), etc. The occurrence of housekeeping service errors, which leads to imperfect rooms, attenuates guests' satisfaction level and hotels' reputation. Under our assembly-line method, attendants perform more simplified and focused tasks, and thus, they become more concentrated and make fewer mistakes.

In summary, our assembly-line housekeeping method has the potential to achieve improvement in three aspects, hygienic standards, labor efficiency, and service quality, at no additional cost.

Of course, there exist issues and difficulties in the implementation of the assembly-line method: for example, how to split tips and how to form teams. We have designed policies to overcome these issues.

We list the main contributions of our work in the following.

- We discovered a crosscontamination channel for infectious diseases during the traditional housekeeping process.
- We designed an innovative assembly-line housekeeping process with the potential to eliminate the contamination possibility.

- We characterized the service time distribution of every single housekeeping operational step.
- We proposed an optimization model to find the best workload allocation plan.
- We compared the assembly-line method with the traditional method in real practice and showed the advantage of the assembly-line method in hygienic standards and labor efficiency, as well as service quality.
- We designed solutions and policies for potential problems that could occur in the implementation of the assembly-line method.

We remark that the principle of the assembly-line method (i.e., separating contaminated tasks from sanitary ones) can also be applied to other service settings. For example, in restaurants, we can assign one group of attendants only to serve dishes and another group only to collect dirty plates. In this way, the new dishes will not be contaminated by the hands of the second group of attendants, which may contain bacteria or viruses from touching dirty plates previously. Such a practice has the potential to effectively prevent disease transmission across tables.

The rest of the paper is organized as follows. In Section 2, we present the background information and literature review related to the hotel housekeeping process. In Section 3, we introduce the data sources and study environments. In Section 4, we analyze the service time data under the traditional housekeeping method. In Section 5, we explain the optimization model for workload allocation. In Section 6, we provide the service time data under the assembly-line housekeeping method. In Section 7, we compare the assembly-line housekeeping method with the traditional method. In Section 8, we discuss potential problems and solutions associated with the implementation of the assembly-line method. In Section 9, we conclude the paper.

2. Background Information and Literature Review

2.1. Hotel Hygiene Issue

Hygiene issue has been a popular discussion topic among hotel guests. Frequent travelers form online communities to log and search for unsatisfactory hotel experiences. Zaldivar (2017) analyzes complaints from hotel guests collected by a hospitality app. It shows that bedroom hygiene condition is the fourth most frequent complaint and makes up 10% of the total complaint volume. Cresswell (2019) states that room cleanliness is travelers' most valued criterion for hotel selection. According to the research, dirty bed linens and disgusting bathrooms are among the top reasons that make guests walk out of a hotel room.

There are many hidden spots in a hotel room that could pose a threat to the health of guests. From Sorene (2012), the countertop and sink of a hotel bathroom become a breeding ground for germs and viruses when attendants place their rubber gloves on them. Diseases such as flu, throat infections, and norovirus can be easily transmitted to hotel guests through touching the shower door glass. The humidity in the bathroom helps the spread of bacteria such as *Escherichia coli* and athlete's foot.

In recent years, there has been an increasing concern about sanitation and hygiene issues in hotel rooms. Disturbing news on guest room cleaning issues has been reported all over the world. In 2016, a decent international brand hotel in the United States was caught not changing bedsheets for new guests. According to Leff (2016), a group of investigators sprayed fluorescent paint on the bedsheets before they checked out of their rooms. Later, they checked in the same room and discovered that the old sheets were not replaced. In 2017, room attendants at several luxury hotels in China were caught using toilet brushes to wash cups and glasses in guest rooms. Numerous news media such as Zhang (2017) reported the incident and posted a short video capturing the violation. Headley (2019) reveals shocking findings in housekeeping practice at high-end hotels from employee surveys. A large percentage of room attendants report that they have witnessed coworkers skipping crucial cleaning steps such as dusting, wiping down surfaces, washing the shower, or vacuuming. One in three attendants has made beds with obvious hair strands on sheets, and two in five attendants have made beds with contaminated linens containing obvious stains. Interestingly, the problem is more severe at five-star hotels than at three-star ones.

Performing an entire hotel room housekeeping procedure involves using multiple designated tools and detergents. Attendants need to switch between many different cloths and brushes. The setup and transition time lead to long completion time of a room and therefore, low throughput. Hotel room attendants are usually paid based on the number of rooms cleaned during their shift. Thus, it is likely that attendants are naturally motivated to skip steps and speed up.

2.2. Hotel Housekeeping Protocol

In recent years, hospitality management experts have published protocols and sample videos on hotel room housekeeping processes. Nowadays, a large percentage of hotels worldwide follow a version of the well-known six-step housekeeping procedure, although the sequence and some details may vary. This six-step method covers all the operational steps that a single room attendant needs to conduct to refresh a checked-out guest room. The first step is removing used bed linens and trash as well as cleaning room surfaces. The second one is making beds. The third one is cleaning the bathroom including toilet, bathtub, shower, sink, mirror, and floor, as well as removing used towels. The fourth one is replenishing items such as towels, toiletries, toilet rolls, and minibar beverages. The fifth one is dusting surfaces of TV, window, and other items. The sixth one is vacuuming the carpet. We refer the readers to Cadieu (2018) and Chant (2018) for detailed descriptions of these steps. On average, a proper completion of all these steps in a regular guest room takes around 30 minutes.

The original housekeeping protocol at JH is a version of the six-step procedure with certain modification. For example, the same as many other Asian hotels, JH offers guests multiple complimentary items such as bottled water, slippers, combs, and toothbrushes. Thus, room attendants have to check the usage of such items and replenish the supply. For dusting, JH asks attendants to cover every corner of the TV, window, and other dusty areas. Attendants use special equipment with a long pole and a disposable cloth to perform dusting. To ensure hygienic standards, JH attendants disinfect bedroom and bathroom surfaces after cleaning. After the completion of the housekeeping operation, every refreshed room has to be checked by a manager before assigned to new guests.

We list the detailed steps of JH's original housekeeping process in Table 1. We see that the crosscontamination of towels and bed linens caused by attendants' contaminated hands and clothes, as mentioned in the introduction (Section 1), happens in between Step (1) and Step (2) as well as in between Step (3) and Step (4).

2.3. Related Literature

Our work mainly contributes to three streams of literature: process improvement, workforce management, and hospitality research.

First, the problem we study is on hotel housekeeping operation improvement through process innovation. Thus, our paper is in general related to the literature on process improvement. Most studies in this research area focus on manufacturing and production systems. For example, Li and Rajagopalan (1998) build a dynamic model to study the relationship between quality and process improvement. Hopp et al. (2007) apply a decision tree to decompose the improvement objective of production lines into logical steps and explain the links between corrective actions and performance. Hopp et al. (2009) use a Markov decision process approach to analyze work in process control policies for production lines. We also refer the readers to Hopp and Spearman (2011) and the references therein for additional models and results. Different from the existing literature, our work looks at the process improvement for hotel housekeeping operations.

Our design of the assembly-line teamwork operation is also linked to the literature on workforce management, particularly for flexible worker assignment in manufacturing and service settings. Bartholdi and Eisenstein (1996) introduce a bucket brigade system in which workers are sequenced along a production flow line; each worker takes a job from the upstream colleague when his or her current job is finished or taken by the downstream colleague. Andradóttir et al. (2001) consider a two-station, two–cross-trained worker service system and find the optimal dynamic workload assignment policy that maximizes the system long-run average throughput. Van Oyen et al. (2001) examine the performance of a simple teamwork policy where all workers form a single team and complete the jobs one after another collaboratively. More recently, Lim et al. (2020) compare various worker assignment policies under the setting of a tandem system with a finite number of heterogeneous jobs. Most of this literature focuses on productivity maximization or cost minimization. Our study, however, has the main objective of improving hygienic standards.

Our paper, of course, contributes to the extensive literature on hospitality research, with a focus on guest room services and housekeeping operations. Steadmon (1974) gives guidelines on how to professionally and profitably manage hotel housekeeping departments through recruitment, orientation, and training. David et al. (1996) look at the relationship between information technology investment and service productivity improvement in the hotel industry. Gundersen et al. (1996) analyze business travelers' assessments on different aspects of hotel stay experience and show that guest room and housekeeping qualities are among the most concerning ones. Siguaw and Enz (1999) summarize U.S. best-practice hotels' efforts on improving operational standards. Enz and Siguaw (2003) study organizational learning in the lodging industry from hotels' refinement and innovation on operations. Lee and Oh (2014) propose effective communication strategies for room attendants to encourage guests to participate in hotel sustainable actions (e.g., reusing towels and forgoing housekeeping). Although the literature uses descriptive models and qualitative analysis to discuss issues in hotel operations management, our paper applies analytical models and quantitative analysis to optimize the guest room housekeeping process. To the best of our knowledge, our work is among the first to improve hotel housekeeping process through data analysis, mathematical optimization, and field test.

3. Data Sources and Study Environments

The analysis and results in this paper involve four parts of data that are collected separately from different

Table 1. JH's Original Housekeeping Process

Steps
Step (1) Cleaning bedroom
Entering bedroom (bringing in bedroom cleaning cloths and disinfectants)
↓
Removing bed linens
↓
Cleaning furniture (e.g., tables, closets, and drawers), doorknobs, and other smudged surfaces
↓
Disinfecting bedroom
↓
Leaving bedroom (taking out used linens and trash to hamper trucks)
Step (2) Making bed
Entering bedroom (bringing in new bed linens)
↓
Making beds
↓
Leaving bedroom
Step (3) Cleaning bathroom
Entering bathroom (bringing in bathroom cleaning cloths and disinfectants)
↓
Cleaning toilet, bathtub, shower, sink, mirror, and counter
↓
Mopping floor
↓
Checking the usage of complimentary items
↓
Disinfecting bedroom
↓
Leaving bathroom (taking out used towels and trash to hamper trucks)
Step (4) Replenishing items
Entering bathroom (bringing in new towels and complimentary items)
↓
Placing all items
↓
Leaving bathroom
Step (5) Dusting bedroom
Entering bedroom (bringing in dusting equipment)
↓
Wiping TV, window, and other dusty areas
↓
Leaving bedroom (taking out dusting equipment and changing disposable cloth)
Step (6) Vacuuming floor
Entering bedroom (bringing in vacuum cleaner)
↓
Vacuuming floor
↓
Leaving bedroom (taking out vacuum cleaner)

channels. In this section, we introduce our data sources and study environments.

Service Time Data Under the Traditional Method from the Field Study

As mentioned in the introduction (Section 1), in order to have a smooth assembly-line housekeeping process, we need to make an even allocation of the workload. The first step for this is to understand the service time distribution of each individual operational step. In our field study at JH, we collected data from the housekeeping practice at hundreds of rooms.

JH is a high-end hotel in a major city in China. It has 140 double rooms and 20 suites in total. The double-room configurations at different hotels of the same level (e.g., high end or medium end) in the same region are usually quite similar. However, the suite configurations could be very different. Thus, to ensure the applicability value of this paper, we only discuss the housekeeping process for the double room. (During the project, we designed assembly-line processes for both double rooms and suites.) Among the 140 double rooms at JH, 100 are twin rooms with two twin beds, and 40 are king rooms with one king bed. Same as the majority in the industry, twin rooms and king rooms at JH contain two categories, standard room and executive room. Although rooms in different categories differ in decoration, furniture brands, TV sizes, and of course, the floor numbers, the general configurations, room sizes, and thus, the housekeeping procedures and times required are the same. Therefore, we only differentiate between twin room and king room but not between standard room and executive room.

JH's yearly average room occupancy rate is higher than 90%. The average number of rooms checked out per day is more than 100. It is trivial to point out that the housekeeping process for a checked-out room and that for a continue-to-stay room are very different. For example, most hotels do not change bed linens in a continue-to-stay room unless requested. In this paper, we only discuss the housekeeping process for checked-out rooms. (During the project, we designed assembly-line processes for both checked-out and continue-to-stay rooms.)

JH has 18 full-time employees in the housekeeping department. All the guest rooms are located on 14 floors. Thus, there are 14 designated floor attendants. Each of them is assigned to a particular floor. The attendant of a floor takes care of all cleaning duties on that floor, which include guest room housekeeping and public area cleaning (e.g., vacuuming the carpet on the corridor and wiping windows and lift doors). From internal statistics, the difference in the monthly average number of checked-out rooms on different floors is neglectable; thus, the workload of the 14 designated attendants is quite fairly distributed. There are another two employees as housekeeping managers. After the completion of housekeeping operation, every refreshed room has to be checked by a manager before being assigned to new guests. The managers also provide noncleaning services to guests. The other two employees in the housekeeping department are hired as night attendants. They serve guests and also perform ad hoc room cleaning (e.g., when a room is messed up by children or drunks) during the night. The managers and night attendants can also be the substitute when a regular floor attendant is on leave.

The service time data of the traditional housekeeping method were collected by two authors of the paper. (Because of the confidentiality agreement, we were not able to hire students or helpers to collect additional data.) All room attendants at JH are full-time employees with a minimum length of service longer than one year. In addition, JH holds a housekeeping protocol and skill training session every month. Thus, the 14 floor attendants are very close to each other in terms of working speed and quality. We randomly selected two attendants for data collection. To collect service time data, the authors followed the attendants throughout the entire housekeeping process and recorded the time spent in each of the six operational steps listed in Table 1. The data recorded in the first two days were eliminated because the attendants claimed that they were too nervous and felt as if they were under surveillance, which affected their performance. Finally, we obtained 74 entries for twin rooms and 66 entries for king rooms on 10 working days. We present and analyze these data in Section 4.

Service Time Data Under the Assembly-Line Method from the Field Study

To evaluate the performance of the assembly-line method, we ran a pilot test. We grouped the two room attendants that we observed for the traditional method into a team. They were trained to follow the assembly-line process and had a three-day trial period to get familiar. Service time data were collected during the housekeeping process. In total, we obtained 50 entries for twin rooms and 50 entries for king rooms on eight working days. (This equal number is because of the fact that because the authors had only limited time to stay at JH, on the last two days of recording, we purposely assigned the attendants to perform housekeeping jobs on selected floors in order to make sure that we could obtain at least 50 samples for both twin rooms and king rooms.) We present these data in Section 6.

Long-Run Hotel-Level Performance Data

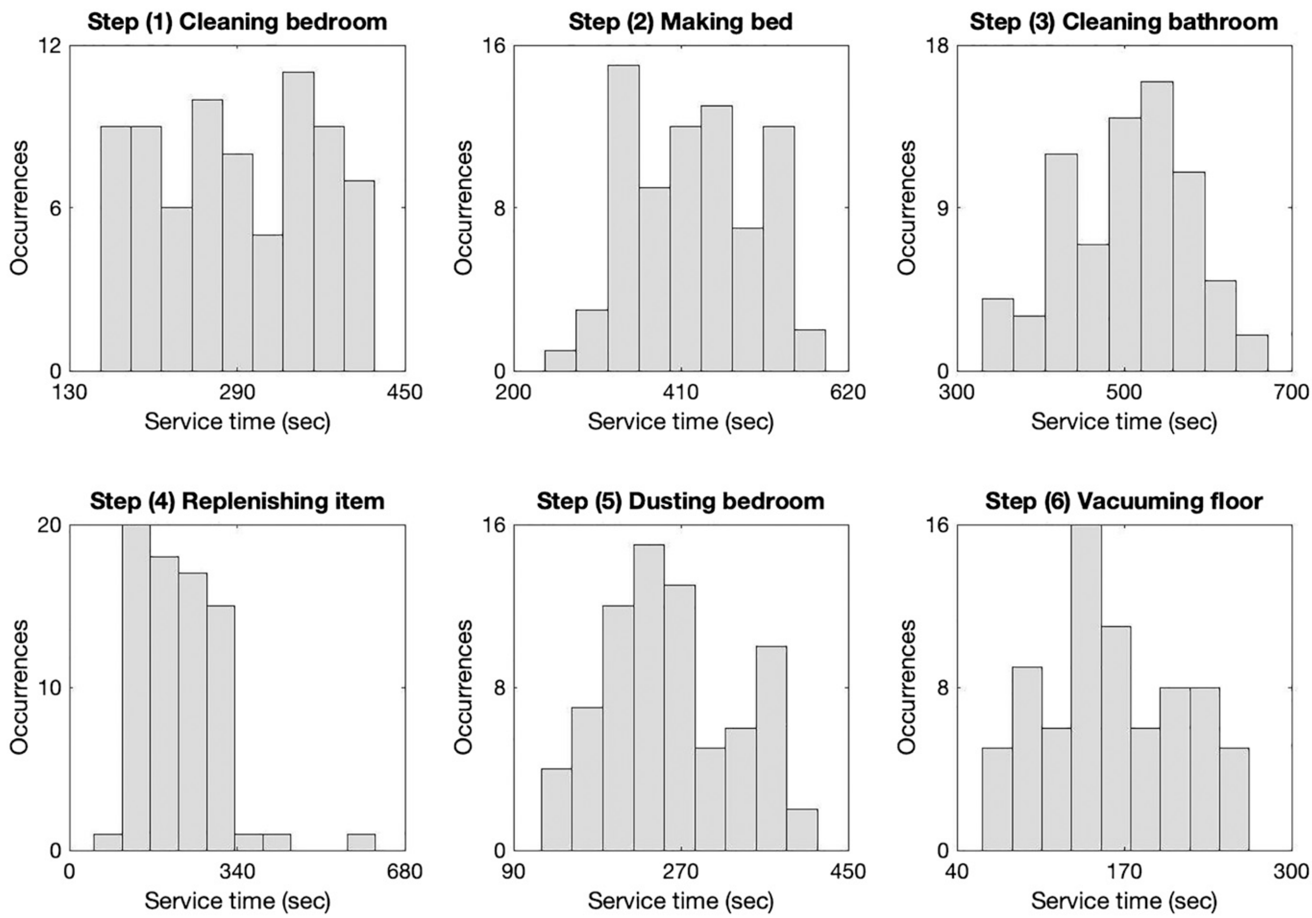
The assembly-line method pilot test was conducted at the end of 2018. Improvement in hygienic standards, labor efficiency, and service quality was observed. Following a training session, this method was implemented by the entire housekeeping department from the beginning of 2019.

To comprehensively show the advantage of the assembly-line housekeeping method, we analyze data on long-run hotel-level performance measures, such as the housekeeping-help request occurrence and the revenue from room sales. The performance in the whole year of 2019 (after the implementation of the assembly-line method) is compared with that in 2018 (before the implementation). We present and analyze these data in Section 7.

Long-Run Customer Review Data

To help to show the benefit of the assembly-line housekeeping method in improving hotel room hygienic standards, we analyze data on customer reviews. From a top online travel agency (OTA), we obtained guest reviews on JH (booked through the OTA) in both years 2018 and 2019. There are a total of 3,040 reviews in 2018 and 3,356 reviews in 2019. Each guest review contains ratings in four metrics: cleanliness, facility, location, and service, as well as comments. To demonstrate the change in hotel room hygienic

Figure 1. Individual Step Service Time—Traditional Method—Twin Room



standards, we look at the score on cleanliness. The individual scores are on a scale of one to five, with one being the lowest and five being the highest. We present and analyze these data in Section 7.

4. Service Time Under the Traditional Method

In this section, we present and analyze data on the service times of individual housekeeping steps under the traditional method. The data source and study environment are introduced in Section 3.

4.1. Data Analysis

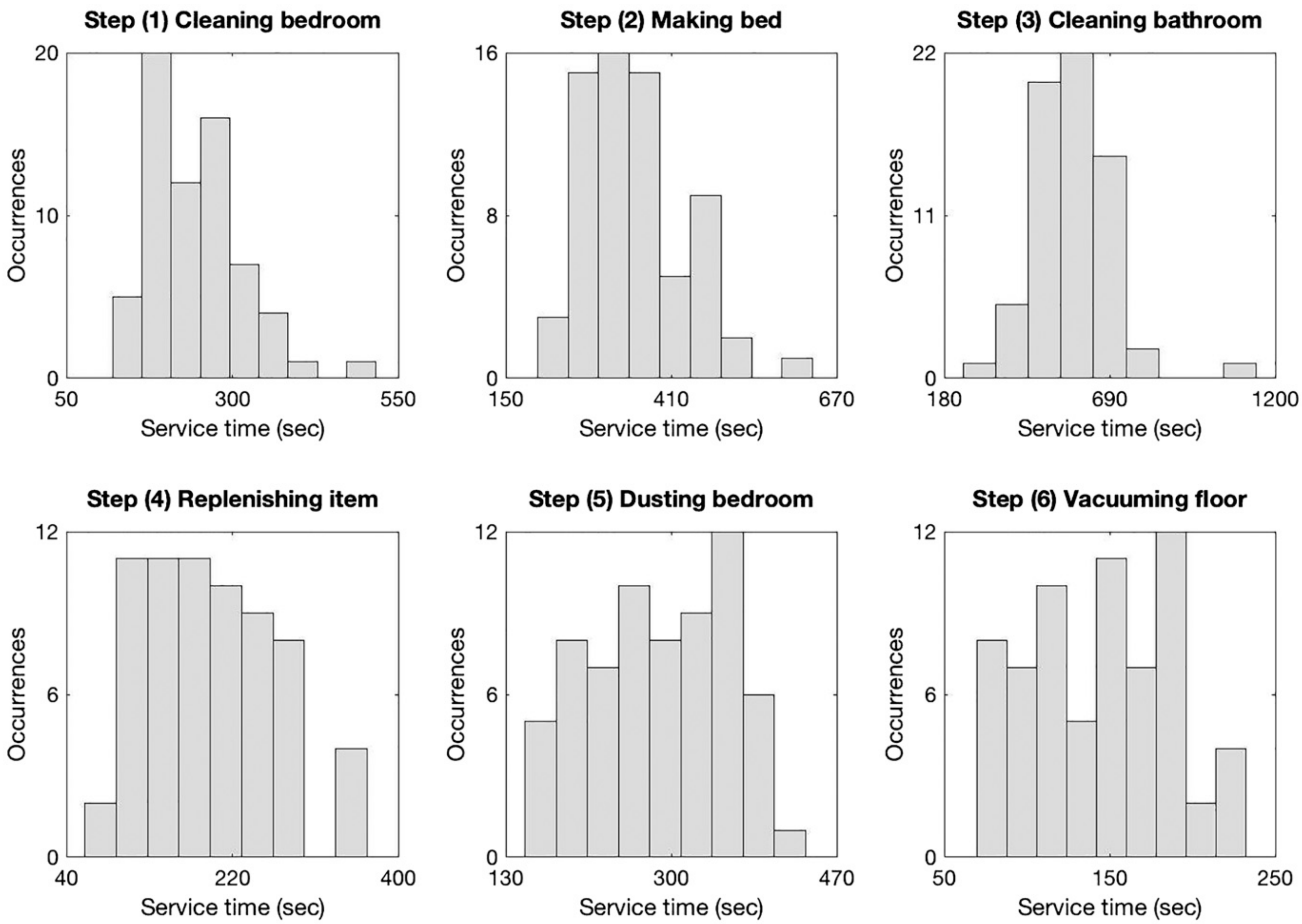
We first present the histograms of service time occurrences for each individual operational step in Figure 1 (for twin room) and Figure 2 (for king room). We then report the mean, standard deviation (SD), and coefficient of variation (CV) in Table 2. For all figures and tables in this paper, time is in units of seconds.

Many interesting and useful facts can be seen from the histograms and the table. First, for the overall average, it takes around 30 minutes to clean a room. This is consistent with the completion time standard given in Chant (2018) under the well-known six-step housekeeping procedure (see Section 2.2 for details). It shows the ability and skills of the room attendants as a result of the rigorous and constant training at JH. More importantly, it justifies the value of our paper, as the attendants and the housekeeping practice at JH represent industry standards.

Next, we see that on average it takes longer to clean a twin room than a king room. The increased workload mainly comes from the first two steps. To explain this, notice that there are two beds in a twin room but only one bed in a king room. Obviously, it takes more time to remove linens and make beds in a twin room.

In general, making beds and cleaning bathroom are the two longest-service time steps among all six. According to the room attendants, these two steps are also the most physically and mentally demanding ones. Performing these two steps back to back is indeed exhausting. To explain why these two steps are particularly challenging, notice that the substeps of making the bed and cleaning the bathroom must be followed exactly in a given sequence. For example, when making beds, attendants must smooth the bedsheet first and then the duvet cover followed by the

Figure 2. Individual Step Service Time—Traditional Method—King Room



pillow. When cleaning bathrooms, attendants must wash the sink before cleaning the counter and clean the counter before mopping the floor to make sure that the cleaned counter and floor will not be contaminated again during later substeps. In contrast, the sequence of many substeps of the other operations can generally be changed. For example, it does not matter too much to wipe tables before doorknobs or vice versa.

When we focus on process variability, we find that the two steps with the highest coefficient of variation are replenishing items and vacuuming floors. This result is quite surprising because these two steps are generally considered as the least difficult as well as the most standardized steps among all. In fact, they are also the two steps with the shortest mean service time. From our observation, the reason behind is that attendants quite often take the step of replenishing items as a half-time break after the first three exhausting steps and the step of vacuuming as a rest session before moving on to another room. Thus, they may intentionally slow down when getting tired. This leads to the high variability in the service times of the two steps.

Table 2. Individual Step Service Time—Traditional Method

	Twin room			King room		
	Mean	SD	CV	Mean	SD	CV
Step (1) Cleaning bedroom	287	74	0.26	242	72	0.30
Step (2) Making bed	426	79	0.19	354	80	0.23
Step (3) Cleaning bathroom	503	74	0.15	577	115	0.20
Step (4) Replenishing item	223	83	0.38	197	70	0.35
Step (5) Dusting bedroom	259	70	0.27	288	69	0.24
Step (6) Vacuuming floor	160	51	0.32	143	42	0.29
Whole room	1858	183	0.10	1801	186	0.10

Taking a closer look at the histograms, we observe that sometimes it takes an extremely long time to complete a task. For example, from the histogram for Step (4) in Figure 1, although the step of replenishing items has an average service time at 222 seconds, there was once where it took more than 600 seconds (i.e., 10 minutes) to finish it. The reason behind this unusual case was that the guest room that corresponds to this data point was extremely dirty and messy after many prohibited conducts (e.g., smoking and cooking with portable stove), and thus, the room attendant was completely

Table 3. Normal Distribution Parameter Estimation—Traditional Method

	Twin room		King room	
	μ CI	σ CI	μ CI	σ CI
Step (1) Cleaning bedroom	(270, 304)	(64, 88)	(225, 260)	(61, 86)
Step (2) Making bed	(408, 444)	(68, 94)	(335, 374)	(68, 96)
Step (3) Cleaning bathroom	(486, 520)	(63, 88)	(548, 605)	(99, 139)
Step (4) Replenishing item	(203, 242)	(72, 99)	(180, 214)	(59, 84)
Step (5) Dusting bedroom	(243, 275)	(60, 84)	(271, 305)	(59, 84)
Step (6) Vacuuming floor	(148, 172)	(44, 61)	(133, 154)	(36, 51)
Whole room	(1815, 1900)	(157, 218)	(1756, 1848)	(159, 225)

exhausted and annoyed. While checking the usage of complimentary items, the attendant could not focus and memorize the details. As a result, the attendant walked back and forth between the bathroom and the housekeeping cart outside the guest room three times and accidentally dropped a new towel set and had to replace it. According to the room attendants, their performance in the later three "easy steps" is often affected by the earlier three "tough steps." When they see a tidier room, they are more delighted; thus, they work faster and make fewer mistakes.

4.2. Service Time Distribution

To the best of our knowledge, there is no empirical study in the literature providing service time distributions of hotel housekeeping operation steps. In this subsection, we fit our field-collected data into distributions. This helps us to better understand and easily describe the service times of individual steps. It can also support future analytical modeling research works.

Following a standard approach, we use the Kolmogorov–Smirnov test to verify whether the service time data fit some common distributions including the exponential, lognormal, normal, and uniform distributions. The results indicate that normal distributions can well fit both the service time data of individual steps as well as that of the whole room. Table 3 reports the 95% confidence intervals (CIs) for the parameter estimates on the mean (μ) and standard deviation (σ) of normal distribution. The sample mean and the square root of the unbiased estimator of the variance are given earlier in Table 2. The histograms on service time occurrences for the whole room and the corresponding normal curves are plotted in Figure 3 (for twin rooms) and Figure 4 (for king rooms) using the MATLAB *normfit* function.

5. Optimization on Workload Allocation

After obtaining the service times of individual housekeeping operational steps, we next work on the assembly-line workload allocation between the two room attendants in a team. The aim is to have an even allocation. In other words, we would like to have the completion time of task C (by attendant C) and that of task S (by attendant S) to be close to each other, so that the two attendants can move smoothly across the rooms with equal speed.

Generally speaking, we can categorize the six steps into three sets in terms of operational requirements and hygienic conditions. (1) *Contaminated step*: steps that can only be assigned to attendant C, such as cleaning the bedroom and cleaning the bathroom. (2) *Sanitary step*: steps that can only be assigned to attendant S, such as making the bed and replenishing items. (3) *Alternative step*: steps that can be assigned to either attendant C or attendant S, such as dusting the bedroom and vacuuming floors. The reason that attendant S cannot perform any of the contaminated steps is that we should not allow the clean hands of attendant S to touch used towels and bed linens, as it breaks the fundamental principle of the assembly-line method and disease transmission could occur. Similarly, attendant C cannot perform any of the sanitary steps.

The alternative steps can be performed by either attendant C or attendant S. This is because, while performing these steps, attendants hold equipment instead of directly touching room items. For example,

Figure 3. Whole-Room Service Time—Traditional Method—Twin Room

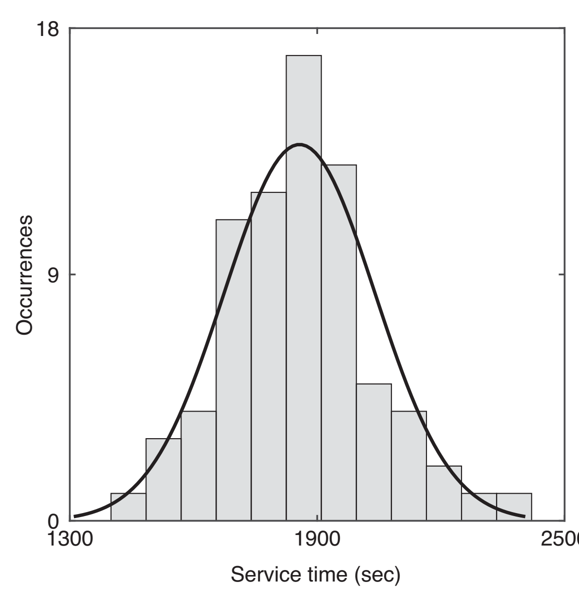
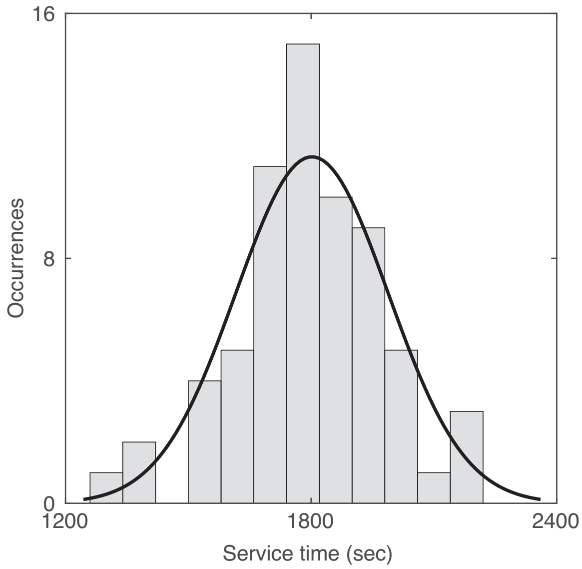


Figure 4. Whole-Room Service Time—Traditional Method—King Room



during vacuuming, the attendant touches only the vacuum cleaner but not the floor. Thus, as long as the two attendants stick to the plan for all rooms and do not hand over the vacuum cleaner to each other, the assembly-line method works no matter who performs the vacuuming step.

With the expected service time of each individual step given in Table 2, we essentially need to allocate those alternative steps to either task C or task S such that the expected completion time of task C and that of task S are close to each other. For our current project with two alternative steps (i.e., dusting the bedroom and vacuuming the floor), there are only four possible allocations in total, and a brute force comparison could quickly lead to the optimal allocation. However, there are many hotels where the housekeeping process involves some extra steps in addition to the common six, and the number of alternative steps could be more than two. For example, we conducted the assembly-line housekeeping method at another resort hotel where each guest room has a balcony. The attendants need to water flowers and mop balcony floor as well as spray air freshener around the room. All these steps belong to the set of alternative steps.

Thus, in order to search for the optimal workload allocation, we introduce the following integer programming formulation:

$$
\begin{aligned}
\min \quad & \left| \sum_{i=1}^{N} t_i x_{i,C} - \sum_{i=1}^{N} t_i x_{i,S} \right| \\
\text{s.t.} \quad & x_{i,C} + x_{i,S} = 1 && \text{for } i = 1, \ldots, N \\
& x_{i,C} = 1 && \text{for } i \in S_C \\
& x_{i,S} = 1 && \text{for } i \in S_S \\
& x_{i,C}; x_{i,S} \in \{0,1\} && \text{for } i = 1, \ldots, N.
\end{aligned}
\tag{1}
$$

To explain this formulation, we first order all the operational steps into a sequence $\{1, \ldots, N\}$. Let S_C and S_S denote the subsets of $\{1, \ldots, N\}$ consisting of steps that have to be performed by attendant C and attendant S, respectively. For $i = 1, \ldots, N$, define $x_{i,C}$ and $x_{i,S}$ to be binary decision variables, such that $x_{i,C} = 1$ if step i is allocated to task C (by attendant C), and $x_{i,S} = 0$ otherwise. Similarly, $x_{i,S} = 1$ if step i is allocated to task S (by attendant S), and $x_{i,S} = 0$ otherwise. t_i represents the expected service time of step i. The objective function minimizes the difference between the expected total service time of task C (expected completion time of attendant C) and that of task S (expected completion time of attendant S). The first constraint guarantees that each step is allocated to either task C or task S but not both. The second and third constraints allocate all steps in S_C and S_S to task C and task S, respectively.

To apply the optimization formulation, the first question is as follows: When plugging in the data on t_i for computation, should we consider twin rooms and king rooms jointly or separately? Essentially, while designing and applying the assembly-line housekeeping method, should we do it for all rooms jointly or for twin rooms and king rooms separately? The answers to these questions depend on the structure of the hotel. If twin rooms and king rooms are well mixed on the floors, then a joint optimization is recommended because otherwise, in order to clean all the assigned twin rooms (king rooms), a housekeeping team needs to move around and across floors in a very complicated way. In contrast, if twin rooms and king rooms are located on different floors as is the case in JH, then separate optimizations could be more favorable. Solving the optimization problem in (1) with the data from Table 2, we obtained the following allocation plan: Attendant C performs Step (1) Cleaning bedroom, Step (3) Cleaning bathroom, and Step (6) Vacuuming floor; attendant S performs Step (2) Making bed, Step (4) Replenishing item, and Step (5) Dusting bedroom for both twin rooms and king rooms. The resulting expected total service times of task C and task S equal 950 and 908 seconds, respectively, for twin rooms, as well as 962 and 839 seconds, respectively, for king rooms.

Notice that every room has to be cleaned first by attendant C (for task C) and then by attendant S (for task S). For the allocation plan, we see that task C has a higher expected service time than task S. It means that, before entering a room, attendant S often needs to wait for attendant C to complete task C in that room. This imbalance creates waste and reduces labor efficiency. Our observation during the field test confirmed this. In addition, we found that attendant S was annoyed that he or she had to wait and waste time frequently. Moreover, seeing attendant S waiting outside the room, attendant C became impatient and sped up, which led to lower service quality.

The opposite case to have, under some alternative allocation plans, is that task S has a higher expected service time than task C. Although imbalance still exists, the situation is much better. For example, if attendant C finishes task C in Room 2 before attendant S finishes task S in Room 1, then attendant C can go ahead to start cleaning Room 3 instead of waiting. Of course, we do not want attendant S to be far behind either because it creates many work in progress rooms not available for guests. To overcome this issue, we designed contingency plans (see Section 8 for details). Moreover, the two attendants do not wait for each other; therefore, they work smoothly without interruption, which ensures service quality. Thus, after a discussion with the attendants and the management team, we proposed an alternative integer programming formulation:

$$\begin{aligned} \min \quad & \sum_{i=1}^{N} t_i x_{i,S} - \sum_{i=1}^{N} t_i x_{i,C} \\ \text{s.t.} \quad & x_{i,C} + x_{i,S} = 1 \qquad \text{for } i = 1, \ldots, N \\ & x_{i,C} = 1 \qquad \text{for } i \in S_C \\ & x_{i,S} = 1 \qquad \text{for } i \in S_S \\ & \sum_{i=1}^{N} t_i x_{i,S} \geq \sum_{i=1}^{N} t_i x_{i,C} \\ & x_{i,C}; x_{i,S} \in \{0,1\} \qquad \text{for } i = 1, \ldots, N. \end{aligned} \tag{2}$$

The added constraint leads to allocation plans where task S has a higher expected service time than task C.

Solving the optimization problem in (2) with the data from Table 2, we obtained the following allocation plan: Attendant C performs Step (1) Cleaning bedroom and Step (3) Cleaning bathroom; attendant S performs Step (2) Making bed, Step (4) Replenishing item, Step (5) Dusting bedroom, and Step (6) Vacuuming floor for both twin rooms and king rooms. The resulting expected total service times of task C and task S equal 790 and 1,068 seconds, respectively, for twin rooms, as well as 819 and 982 seconds, respectively, for king rooms. Although this plan makes the workload of attendant S higher than that of attendant C by a few minutes, attendant C does not need to waste time and wait. After attendant C finishes all the rooms to be cleaned, he or she can proceed to clean public areas. In addition, from the field test, we discovered that because cleaning the bathroom is extremely exhausting, attendant C needs to take a short break before moving on to another guest room. Thus, the gap in service times is beneficial.

We are not claiming that the allocation plan from solving optimization Problem (2) always outperforms the one from solving (1). Notice that an allocation plan with the expected service time of task C being a few seconds higher than that of task S would be a good one. However, it is infeasible under (2). In general, we recommend solving both optimization Problems (1) and (2) and comparing the corresponding allocation plans with practical concerns that are applicable to the particular hotel.

We remark here that there exist situations where additional constraints need to be added to the optimization problems. It usually happens when the sequence of certain housekeeping steps has to be persisted. For example, at the previously mentioned resort hotel, attendants need to water flowers on the balcony in addition to the six standard steps. Although watering flowers belongs to the set of alternative steps (and can be allocated to either attendant), we have to make sure that this step is performed ahead of vacuuming the floor. Otherwise, the sand and dust brought to the bedroom from the balcony on the attendant's shoes will be left on the bedroom floor. Suppose step j represents watering flowers and step k represents vacuuming the floor; we need to add the constraint

$$x_{j,C} \geq x_{k,C}$$

to the allocation optimization problem.

6. Service Time Under the Assembly-Line Method

In this section, we present data on service time under the assembly-line housekeeping method. The data source and study environment are introduced in Section 3.

The procedures of the assembly-line housekeeping process at JH are summarized in Table 4. The occurrence histograms and the means, standard deviations, and coefficients of variation of the service time of each individual operational step are reported in Figures 5 and 6 and Table 5. Notice that we have renumbered the operational steps according to the new sequence in Table 4.

We see that under the assembly-line method, the service times of individual operational steps had changed. (See the comparison of the two housekeeping methods in Section 6 for details.) Solving the optimization problem in (2) again with the new data from Table 5, we obtained the same allocation plan. The resulting expected total service times of task C and task S equal 733 and 903 seconds, respectively, for twin rooms, as well as 679 and 751 seconds, respectively, for king rooms.

7. Comparison of Housekeeping Methods

In this section, we describe the advantages of the assembly-line housekeeping method by comparing it with the traditional method, in various aspects. We first make the comparison using data from field studies. We then add to the comparison using data on long-run

Table 4. JH's Assembly-Line Housekeeping Process

Attendant C
Step (1) Cleaning bedroom
↓
Step (2) Cleaning bathroom
Attendant S
Step (3) Making bed
↓
Step (4) Replenishing item
↓
Step (5) Dusting bedroom
↓
Step (6) Vacuuming floor

hotel-level performance measures. The data sources and study environments are introduced in Section 3.

7.1. Field Study Result Comparison

Labor Efficiency. We first look at the performance of the assembly-line method on labor efficiency.

To compare the numbers in Tables 2 and 5, we define

$$\frac{\text{service time under traditional method} - \text{corresponding service time under assembly-line method}}{\text{service time under traditional method}} \times 100\%$$

as *percentage reduction* and report the results in Table 6.

We see that the assembly-line method leads to service time reduction in every single operational step. In terms of the average service time of the whole room, the percentage reductions are as much as 12% for twin rooms and 21% for king rooms. From the coefficient of variation, we see that service time variability also decreased tremendously. In addition, comparing the histograms, we see fewer occurrences of extremely long service time in individual steps. Thus, the assembly-line housekeeping method can achieve remarkable improvement in labor efficiency. To explain this improvement, we point out two facts. First, under the assembly-line method, attendants do not need to walk between the guest room and housekeeping cart as many times as they do under the traditional method. Second, under the assembly-line method, attendants do not need to switch among many different operational steps as they do under the traditional method. When workers are focused on fewer tasks, they work faster.

To verify whether the service time reduction is significant, we apply Welch's t-test (unequal variances t-test) to compare the mean service times under the traditional and the assembly-line methods. For each room type and operational step, the null hypothesis states that the mean service time under the traditional method is greater than or equal to that under the assembly-line method. We let $\alpha = 0.05$ for the tests. Results on the p-value and power are reported in Table 7.

We see that for twin rooms, all the service time reductions are significant, except for Step (2). From Table 6, the mean service time of Step (2) under the assembly-line method is close to that under the traditional method (1% reduction). For king rooms, all the service time reductions are significant. The powers of

Figure 5. Individual Step Service Time—Assembly-Line Method—Twin Room

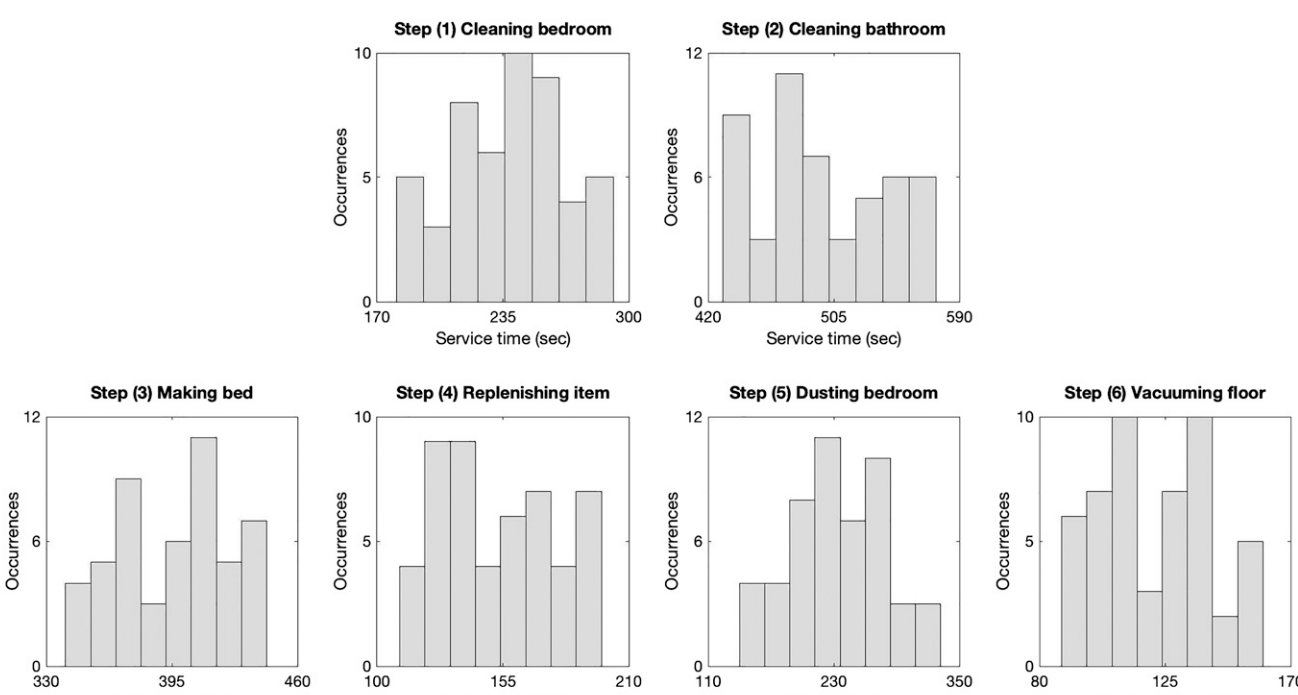
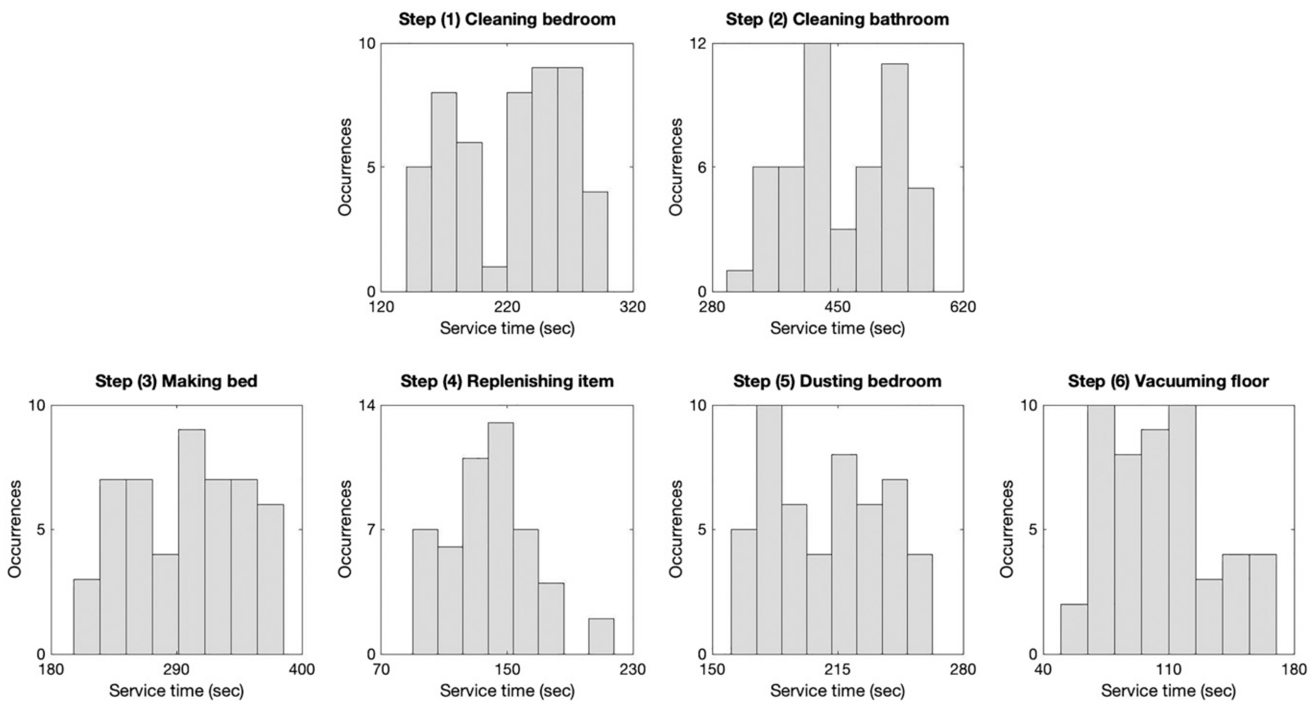


Figure 6. Individual Step Service Time—Assembly-Line Method—King Room



the tests are high, except for Step (1). From Table 6, Step (1) receives the lowest improvement in mean service time (8% reduction) among all operational steps.

Service Quality. In addition to the improvement in labor efficiency, another benefit of making attendants focus on fewer tasks is the clear drop in housekeeping service error rate.

Errors in housekeeping service refer to the imperfect conditions in refreshed guest rooms because of the carelessness of room attendants during housekeeping operations. Typical errors include leftover trash, uncleaned drawers, incorrect count of towels, missing bottled water (in hotels offering complimentary water for guests), etc. The occurrence of housekeeping service errors, which leads to imperfect rooms, attenuates guests' satisfaction level and hotels' reputation. At JH, every refreshed room is checked by a manager after the completion of housekeeping operations. When the manager finds an error, he or she either fixes it himself or herself or calls attendants to come and work on it.

During the field study period, the managers recorded the number of occurrences for all housekeeping service errors. Under the traditional housekeeping method, the average error rate was 4.2 per room. This number reduced to 2.0 under the assembly-line method, which shows a remarkable 52% improvement. We see that when workers are focused on fewer tasks, they become more concentrated and make fewer mistakes.

We remark here that, because it is too tedious and time consuming to write down the details of all service errors, the housekeeping managers simply counted and reported to us the number of occurrences. According to the managers, the reduction in error rate is mainly because of the better completion for operational steps of replenishing items and

Table 5. Individual Step Service Time—Assembly-Line Method

	Twin room			King room		
	Mean	SD	CV	Mean	SD	CV
Step (1) Cleaning bedroom	237	30	0.13	223	46	0.21
Step (2) Cleaning bathroom	496	43	0.09	456	69	0.15
Step (3) Making bed	396	29	0.07	299	49	0.16
Step (4) Replenishing item	153	25	0.17	138	28	0.20
Step (5) Dusting bedroom	233	45	0.19	209	30	0.14
Step (6) Vacuuming floor	121	20	0.17	105	29	0.28
Whole room	1636	79	0.05	1430	113	0.08

Table 6. Percentage Reduction

	Twin room			King room		
	Mean	SD	CV	Mean	SD	CV
Step (1) Cleaning bedroom	17%	59%	50%	8%	36%	30%
Step (2) Cleaning bathroom	1%	42%	40%	21%	40%	25%
Step (3) Making bed	7%	63%	63%	16%	16%	30%
Step (4) Replenishing item	31%	70%	55%	30%	60%	43%
Step (5) Dusting bedroom	10%	36%	30%	27%	57%	42%
Step (6) Vacuuming floor	24%	61%	47%	27%	31%	3%
Whole room	12%	57%	50%	21%	39%	20%

Table 7. *t*-Test Statistics

	Twin room		King room	
	p-value	Power	*p*-value	Power
Step (1) Cleaning bedroom	10^{-7}	1.00	0.03	0.52
Step (2) Cleaning bathroom	0.26	0.14	10^{-10}	1.00
Step (3) Making bed	0.001	0.82	10^{-6}	1.00
Step (4) Replenishing item	10^{-10}	1.00	10^{-9}	1.00
Step (5) Dusting bedroom	0.005	1.00	10^{-13}	1.00
Step (6) Vacuuming floor	10^{-8}	1.00	10^{-8}	1.00
Whole room	10^{-15}	1.00	10^{-25}	1.00

making beds. In other words, missing items (e.g., slippers or toothbrushes) and imperfect beds (e.g., unsmooth bedsheet or pillow) happen much less frequently. Notice that under the traditional method, the step of replenishing items is conducted right after the two longest-service time steps (i.e., making the bed and cleaning the bathroom). When attendants are exhausted, it is difficult for them to be focused. Thus, they make more mistakes in counting and replenishing complimentary items. For the step of making bed, as we explained in Section 4.1, attendants' performance in housekeeping operations can be affected by the conditions of the checked-out rooms. When they find extremely dirty and messy rooms, they are more likely to be annoyed, which increases their possibility to make mistakes in work. Under the new assembly-line method, the steps of making the bed and replenishing items become the first two tasks for attendant S. In addition, attendant S only enters rooms that are already cleaned by attendant C. Thus, he or she is less fatigued and more delighted while working and makes fewer mistakes.

7.2. Long-Run Hotel-Level Performance Comparison

Hygienic Standards. The most important benefit of the assembly-line method is the improvement in hygienic standards. This innovative process design prevents contaminated hands and clothes of room attendants (after holding used towels and bed linens) touching new towels and bed linens and thus, has the potential to eliminate the transmission channel of infectious diseases. Because of the confidentiality agreement, we cannot publish bacteria load testing results in this paper. Instead, we use customer online reviews as a proxy to show the change. The data source is introduced in Section 3.

To report preliminary findings, Table 8 shows the distribution of the cleanliness ratings for both years of 2018 and 2019. We see that overall JH received excellent ratings on room cleanliness. The average score equals 4.855 in 2018 and 4.860 in 2019, and the majority of guests (>88%) gave full points (5) in both years. To better illustrate the improvement, Figure 7 plots the occurrence of unsatisfied (1 to 3 points) and satisfied (4 to 5 points) cleanliness reviews in both years. We see that both the number of occurrences and the percentage of unsatisfied reviews dropped, whereas the same measures for satisfied reviews rose in 2019. All of these indicate the potential of the assembly-line method in improving hygienic standards.

Labor Efficiency. The pilot test data clearly show the high labor efficiency achieved under the assembly-line housekeeping method. This advantage can be further supported by several long-run hotel-level measures.

The peak period for guest check-in at JH is 14:00–16:00. Thus, JH would like to have as many rooms available by 14:00 as possible. The housekeeping manager checks the task completion status of each attendant (team) at 12:00 each day. When an attendant (team) has a low room completion rate (i.e., a high number of assigned but unfinished rooms) by then, the manager will request other available attendants to help.

Figure 8 draws the aggregate housekeeping-help request occurrences in each month of 2018 and 2019. The monthly average dropped from 67 requests in 2018 to 39 requests in 2019, which shows a 42% reduction.

In addition, the JH housekeeping manager performs another task completion status check at 14:00 each day and records the number of checked-out rooms that have been cleaned by then. The daily average increased from 107 rooms in 2018 to 122 rooms in 2019, which shows a 14% raise. All of these indicate the benefit of the assembly-line method in improving labor efficiency.

Other Aspects. It is generally known that excellent hotel services and therefore, great guest reviews could help to attract more future customers and thus, improve hotels' financial performance. Figure 9 shows JH's revenue from room sales in each month of 2018 and 2019. The monthly average increased from 1.85 million yuan (CNY) in 2018 to 1.95 million CNY in 2019, which shows a 5% raise.

As a summary, from all the comparisons, we conclude that the assembly-line housekeeping method has the potential to improve not only hygienic standards but also, labor efficiency and service quality.

Table 8. Cleanliness Rating

	"1"	"2"	"3"	"4"	"5"	Mean (SD)
2018	7 (0.23%)	8 (0.26%)	59 (1.94%)	270 (8.88%)	2,696 (88.68%)	4.855 (0.441)
2019	6 (0.18%)	5 (0.15%)	53 (1.58%)	326 (9.71%)	2,966 (88.38%)	4.860 (0.427)

Figure 7. Unsatisfied vs. Satisfied Reviews

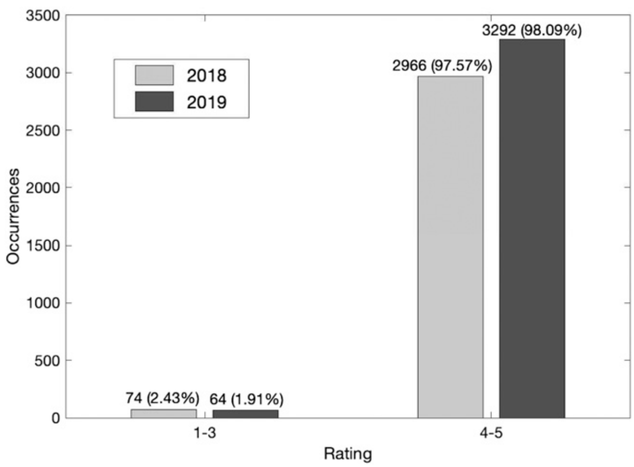
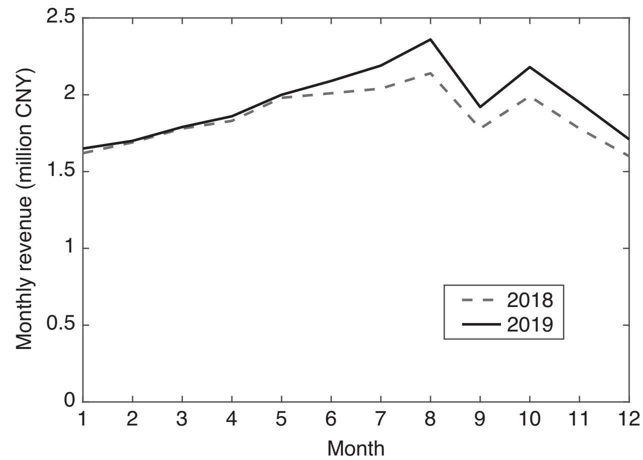


Figure 9. Hotel's Revenue



Hotels' financial performance could also ultimately benefit from such a multidimensional improvement.

8. Implementation Suggestions

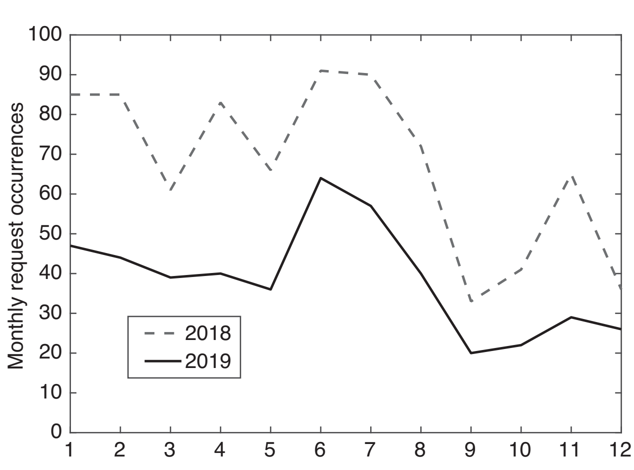
Apart from the various advantages, there also exist potential problems and difficulties associated with the implementation of the assembly-line housekeeping method. In this section, we discuss the problems we came across during the implementation at JH and our solutions.

Who should be attendant S and who should be attendant C?

It is quite natural and understandable that all workers prefer to be attendant S because task S is less physically demanding, and there is no close contact with contaminated items (e.g., toilet).

To make a fair assignment, our recommendation is to do a daily *rotation*. In other words, the two attendants in a team switch roles after each day of work. In this way, every worker takes the role of attendant S and the role of attendant C for half of the time.

Figure 8. Housekeeping-Help Request



How to pair attendants to form teams.

Pairing attendants to form teams is an essential and important step for the implementation of the assembly-line housekeeping method. Should the manager assign teams or let the workers form their own teams? This dilemma exists in all settings where teamwork and coordination are involved.

The guiding principle is that the two attendants in a team should be similar in working speed and quality. We suggest that the attendants form teams themselves. A good relationship between teammates helps in several aspects (see the discussion later in this section).

What if one team member takes a leave?

When one attendant of a team takes a day off, we have to pair his or her teammate with someone else (e.g., another attendant whose teammate is also taking a day off, a manager, or a night attendant) to form a temporary housekeeping team. This could affect the efficiency as well as service quality. Thus, it is preferred that the two attendants of the same team take leave simultaneously. In this case, we could ask another team to cover the workload (with either extra pay or future credit).

At JH, incentives such as cash rewards are provided to attendants who schedule and take leaves together with their teammates. Notice that one benefit of letting attendants form their own teams is the easy coordination of taking leaves.

Who will collect the tip?

Many hotel guests leave tips in the room. Under the assembly-line method, attendant C is the first one to enter a guest room and thus, the first one to see the tip. Although there is a daily rotation of the roles, it still makes attendant S unhappy without getting any tip on that day. Sometimes, a guest leaves a huge tip for the excellent service received, and it is not fair if attendant C keeps it himself or herself.

It is not difficult to solve this problem with the current mobile payment technology. We can simply put a quick response (QR) code for tipping in each guest room. When a guest scans the QR code to give a tip, the amount will be evenly distributed to the two attendants.

What happens if one attendant is far behind the schedule?

Although the workload allocation plan between the two attendants is optimized and leads to a smooth process most of the time, it does happen occasionally that one attendant is far behind the schedule. There are usually two scenarios. First, attendant C is delayed by extremely messy bedrooms and bathrooms; thus, attendant S is delayed to enter rooms. Second, attendant S is delayed by making additional beds (e.g., sofa beds or baby cots); thus, there exist multiple work in progress rooms that are not available for guests. Both scenarios lead to lower efficiency and service quality.

To avoid these unfavorable scenarios, we recommend the following contingency plan. First, when attendant C encounters an unusually messy guest room and estimates the completion time to be much longer than the average, he or she needs to check the status of attendant S. If attendant S is already in the predecessor room and expects to finish after the length of an average service time, then attendant C needs to call the manager for help. Similarly, when attendant S faces a room with the demand for making additional beds, he or she needs to check the status of attendant C. If attendant C is already two rooms ahead of attendant S, then attendant S needs to call the manager for help. When a request is received, a manager will come to help. In the case that managers are not available, an attendant from another team can be sent to help.

To complete the discussion, in the case that attendant S needs to wait for attendant C but the estimated waiting time is only a few minutes, attendant C should simply take a break. Help should not be requested. Again, a good relationship and mutual understanding between the teammates are important.

Are there any additional suggestions to improve process efficiency?

As mentioned in Section 3, the housekeeping process for a checked-out room and that for a continue-to-stay room are very different. For example, most hotels do not change bed linens in a continue-to-stay room unless requested. Thus, we need to design different workload allocation plans for these two types of rooms. In addition, the usual time for cleaning checked-out rooms and continue to stay rooms are different. Checked-out rooms can only be cleaned after guests check out, whereas most continue to stay rooms are cleaned when guests are having breakfast. Under the assembly-line housekeeping method, a housekeeping team is in charge of all assigned guest rooms on one or multiple floors. In order to clean all the checked-out rooms, the two attendants need to move around and across floors. It is obvious that the process will become much more smooth and efficient if an entire floor only consists of checked-out (continue-to-stay) rooms or at least all checked-out (continue-to-stay) rooms are adjacent.

At JH, to smooth the housekeeping process, we assign rooms to guests based on their checkout dates. Except for those who have preferences on the floors to stay, guests with the same checkout dates are assigned on the same floor. This effort tremendously reduces the walking distance of attendants and greatly improves the process efficiency.

9. Conclusion

This paper documents a field study on hotel housekeeping process innovation. We found that room attendants' action of touching new towels and bed linens immediately after contacting the used ones could have created a transmission channel for infectious diseases. To prevent the contamination, we designed an innovative assembly-line housekeeping process, where two attendants form a team and perform the housekeeping of guest rooms in sequence. The attendant who takes charge of the contaminated steps (e.g., cleaning bedrooms and cleaning bathrooms) never touches new towels and linens, whereas the other attendant who takes charge of the sanitary steps (e.g., making beds and replenishing items) never touches used towels and linens. In this way, we break the contamination channel. In order to make an even allocation of workload between the two attendants, we collected field data from the housekeeping practice at hundreds of rooms. We analyzed the data and characterized the service time distribution of every single operational step. We proposed optimization models to search for optimal workload allocation plans. Through a pilot test, we showed that the assembly-line housekeeping method has the potential to improve not only hygienic standards but also, labor efficiency and service quality (error rate). We also designed solutions for potential problems that could occur in the implementation of the assembly-line method.

We emphasize that the principle of the assembly-line method (i.e., separating contaminated tasks from sanitary ones) can be applied to not only hotel housekeeping practices but also, other service operations. For example, in restaurants, we can assign one group of attendants only to serve dishes and another group only to collect dirty plates. In this way, the new dishes will not be contaminated by the hands of the second group of attendants, which may contain bacteria or viruses from touching dirty plates previously. Such a practice has the potential to effectively prevent disease transmission across tables, which is particularly crucial under a disease outbreak where high viral load exists in the saliva of infected patients, such as the COVID-19 pandemic.

For future research, there are several meaningful directions. First, because of our confidentiality agreement with JH, we cannot publish bacteria load testing results in this paper. In the future, it will be useful to test the assembly-line method at other hotels where bacteria load testing results can be published. This helps to directly prove the usefulness of the assembly-line method in improving hygienic standards. Second, for our field study at JH, because it is too tedious and time consuming to write down the details of all service errors, the housekeeping managers only reported to us the number of service error occurrences, without detailed summary statistics. In the future, it will be meaningful to conduct additional field studies and record the details of service error occurrences. This helps to further analyze the benefit of the assembly-line method in improving service quality. Third, in this work, for the optimization of workload allocation, we only use information on the mean service times. In the future, it will be interesting to study workload allocation plans while taking into consideration the variability of service times. Last, this paper only reports the findings based on one high-end hotel. In the future, it will be valuable to study the assembly-line method at multiple hotels at different locations, of different sizes, and targeting different customer segmentations. Because of the current COVID-19 pandemic, it is difficult for us to travel and conduct field experiments. We hope that our assembly-line process design can help to prevent disease transmission and contribute to the restart of the service industry. With all the efforts from healthcare workers, academicians, practitioners, and all citizens, we can conquer this crisis together.

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