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Hotel Engineering Facilities: A Case Study of Maintenance Performance

Abstract

Many hotels are using computerised maintenance management systems (CMMS) to organize building and facility maintenance works. The data recorded by a CMMS are useful information to assessment of maintenance performance but few have paid attention to this application. The findings of a pilot case study conducted based on a 618-room hotel in Hong Kong, as reported in this paper, include how the hotel's CMMS was utilized to facilitate maintenance work organization and the analyses of the CMMS records and associated documentary information for a 12-month period. The study revealed that the maintenance workload was dominated by electrical installations, and the guestrooms demanded for far more maintenance works than the other areas. Significant correlation was found between equipment downtime and amount of maintenance work orders. A range of performance curves and indicators which is useful for assessing maintenance performance of hotel engineering facilities is also presented.

Keywords: Benchmarking; computerised maintenance; facility management; hotel; performance evaluation

1. Introduction

Hotels are one of the key pillars of the tourism industry. Hotel patrons typically have a high expectation on service quality and can easily be upset by unsatisfactory services. Besides services rendered directly by hotel workers, such as concierge and housekeeping, the functions served by engineering facilities in a hotel are no less critical to keeping patrons satisfied. Unsatisfactory performance of such facilities can erode the reputation and profitability of a hotel while reduced profit means fewer resources available for maintenance and retrofit, which could result in a vicious circle.

Maintenance works for a hotel may be broadly classified into building maintenance works (e.g. fabric, grounds and furniture) and building services maintenance works. The latter cover electrical, air-conditioning, plumbing, drainage and fire protection systems, and others. For most hotels, the volume and complexity of maintenance works warrant the establishment of an engineering department dedicated to deal with these works (DeFranco and Sheridan, 2007). To enable prompt tracking of the status of maintenance works, more and more hotels are equipped with a computerised maintenance management system (CMMS), which not only records the data pertaining to the maintenance works but also automates the administrative procedures associated with the works.

Whereas advices on the considerations that should be taken in using a CMMS are available (e.g. Levitt, 2007), how such systems are being used to also evaluate facility performance and maintenance management performance is largely unknown. Because maintenance information, such as frequency of equipment faults, downtimes, repair costs, etc., is often regarded as too sensitive to disclose (Lai et al., 2008), empirical findings on maintenance performance are scarce. In fact, the general lack of research on the impact of information technology (IT) on the qualitative aspects of hotel performance had been identified long ago (Sheldon et al., 1987). Since then, many surveys (e.g. Armijos et al., 2002; Law and Jogaratnam, 2005) and reviews (e.g. O'Connor and Murphy, 2004; Law et al., 2009) were carried out to investigate the trends or applications of IT in the hospitality industry. However, researches that pinpoint at the use of CMMS in hotels are yet to be seen.

Only a paucity of articles that address maintenance performance of hotels could be found from a search of the open literature. Although Chan et al. (2001) attempted to develop a few performance indicators for measuring the effectiveness of maintenance for hospitality engineering systems and some maintenance cost benchmarks for luxury hotels have been made available from a more recent study (Lai and Yik, 2008), in-depth research findings about workload, input manpower and outcome of maintenance works for hotel engineering facilities remain unavailable. Without such information, performance of maintenance works could not be evaluated, not to mention comparison or benchmarking of performance.

As a first attempt to fill the above knowledge gap, a case study has been carried out recently based on the maintenance data of a quality hotel in Hong Kong. Reported in this paper includes a brief account of the hotel's characteristics, how its CMMS was utilized and the kinds of data that were retrieved from the CMMS for the purpose of this study. The analyses on the maintenance workloads, manpower input and performances of the facilities are then presented together with the resultant indicators and benchmarking curves that can be used for performance evaluation.

2. The Maintenance Processes and Data

The study was based on a 4-star hotel housed in a 19-storey, 33-year old building, which accommodated 618 guestrooms. The gross floor area of the hotel was over 39,000m^2, among which the non-guestroom areas such as function rooms, food and beverage outlets and kitchens collectively amounted to 4,053 m^2. The air-conditioned areas, including the guestrooms, were served by distributed fan-coil units and the interior spaces were illuminated mainly by incandescent lamps.

Bearing an international brand, the hotel was equipped with quality engineering facilities, which were looked after by an engineering department headed by a Director of Engineering. Over the years, phased renovation works were carried out for the hotel. Typically three storeys of guestrooms were grouped for renovation over a 3-month period and the frequency of such renovations, depending on the condition of the guestrooms, ranged from 10 to 15 years. With a similar frequency, the renovations for up to two functions rooms or food and beverage outlets were completed between two and four months. For the recent year, the repair and maintenance cost was HK$7.0 million and the maintenance staff payroll was HK$5.1 million. The total of these expenditures was slightly less than the hotel's energy cost, which was HK$15.4 million. The proportion between them was comparable to the average value found from a benchmarking study on a group of luxury hotels in Hong Kong (Lai and Yik, 2008).

Being exploratory in nature, the study commenced with a kick-off meeting with the relevant hotel staff for discussing the scope and objectives of the study and the information that could be gathered to underpin the study. At this meeting, the Director of Engineering and his colleagues briefed the study team about the major facilities in the hotel; how the maintenance works were organized and executed; and the process for recording maintenance data with the use of the CMMS. After the meeting, the study team paid a walk-through visit to the main and typical areas in the hotel to acquaint themselves with the nature and scale of the facilities, and was also admitted to the Service Centre where the main terminal of the CMMS system was located, to observe the operations of the system.

Subsequently, the study team was provided with factsheets that show the number of storeys, floor areas and types and quantities of various premises of the hotel. The maintenance data stored in or generated by the CMMS over a 12-month period were collected. The data included an annual report generated by the CMMS, which contains summary statistics of the maintenance requests for various kinds of jobs handled by the engineering department.

Another set of data obtained, also generated by the CMMS, was a *Detail Listing of Service Request Report*, which lists out all the maintenance orders issued over the year including, for each order, the date, start time, finish time, duration of work completion beyond the prescribed time limit, location of work, work description, and identities of the Service Agent who entered the order's information into the CMMS and the Service Runner who performed the maintenance work as the order required. The prescribed time limits for completing maintenance work orders are given in another file collected, to allow assessment to be made of the speediness of maintenance work. The last type of data collected are the technicians' duty schedules, from which who were on duty or on leave in each of the four shifts per day can be identified, was essential information for assessing the manpower utilization level.

Since the hotel staff had no prior experience with such a study, the above types of data were not readily available at the outset; they were gathered by the hotel staff and provided to the study team in batches and, in a number of cases, the data provided were incomplete or unclear in the first place. Three more meetings with the responsible staff, during which further discussions were made over the data requirements and the queries found from the collected data, were held before all the outstanding data were obtained and the queries cleared.

In the engineering department, under the Director of Engineering there was an Assistant Director who managed the maintenance team, which included a Building Maintenance Engineer who was leading four Duty Engineers and four Foremen. The Foremen were each supervising a group of in-house technicians in one of the four specialized trades (Figure 1), namely air-conditioning (AC), electrical (EL), plumbing and drainage (PD), and builder's work (BW). Statutory maintenance works that must be undertaken by licensed contractors (Lai and Yik, 2004), e.g. those for lifts and fire services, were outsourced.

'Insert Figure 1 here'

For the hotel it serves, the CMMS runs round the clock every day. As Figure 2 depicts, a maintenance work order would typically originate from a call to the Call Centre through a dedicated telephone line. In response, the Service Agent would see if the request entails maintenance work and, if so, he would create a work request through the CMMS and, taking into account the trade of the required work and the specialty of technicians, send through the CMMS a short message service (SMS) to the most appropriate technician (i.e. the Service Runner). The Runner, having been informed of the job details, would go to the scene and carry out the required work. In case more time is needed for accomplishing a work for which a completion time limit had been preset, the Runner would request the relevant Duty Engineer to authorise through the CMMS an extra time allowance. Upon work completion, he would report it to the Service Agent and the work order would be concluded.

'Insert Figure 2 here'

The CMMS can display at its main terminal real-time information, such as time of incoming call and call status (waiting on-line, abandoned before answering or message left in the voice mailbox), and other information, such as guest identity and room number. Apart from allowing prompt tracking of the status of requests, the CMMS would record key information of the requests, including start time, finish time, location of work and identities of the responsible Agents and Runners. In addition, statistical summaries about the total number of requests and the number of the most frequent types of work requests could be generated as and when required. The CMMS, however, was not built-in with some more in-depth analysis functions, such as those presented below.

3. Data Analysis and Discussion

3.1 *Maintenance Workload*

The 12-month CMMS record collected and analyzed in the present study comprised a total of 17,799 maintenance requests (i.e. work orders). This is equivalent to 28.8 orders per room-year, or 23.6 orders per room-year after discounting those that were unrelated to the guestrooms. As summarized in Table 1, the trade that accounted for the greatest number of orders was electrical (EL), followed by plumbing & drainage (PD), builder's work (BW) and air-conditioning (AC). Owing to unclear descriptions that even the hotel staff were unable to clarify, 331 orders could not be classified.

'Insert Table 1 here'

As noted earlier, the back of house area accounts for about 10% of the building area, with the guestrooms being the major part of the hotel. Similar to the proportions between these areas, the majority of the orders were issued for maintenance works in the guestrooms (81.9%), which is most noticeable for the PD trade (Table 1). The share of orders for the non-guestroom areas was the highest for AC works but the lowest for PD works. When the orders were grouped with reference to the guestrooms' renovation history, it was found that on average 824 orders were issued for each storey of guestrooms that had been renovated in the past five years whereas significantly more orders (1,169) were issued for those without renovations for 15 years.

The total number of work orders in each month was counted to unveil the monthly variations. During this process, it was found that work order records in two periods (18-30 June and 29-30 September) were lost due to breakdowns of the CMMS. To enable comparisons to be made on an equal basis, the problem with lost data was solved by dividing the total number of work orders in each month with missing data by the actual number of days with data to yield an average number per day in the month. This means that the work orders issued on days with missing data were assumed to be equal to the average number so calculated. Furthermore, a normalized monthly mean daily number of orders ($\hat{N}_{O,m}$) was computed using Equation (1), where $N_{O,m}$ and $N_{D,m}$ are respectively the number of orders issued and the number of days in the m^{th} month.

$$\hat{N}_{O,m} = \frac{N_{O,m}}{N_{D,m}} \tag{1}$$

Figure 3 shows both the number of work requests and the normalized mean daily number of orders (i.e. number of requests per day) in each month. The requests per day from the guestrooms peaked in April (52.3) while the trough was in February (34.7). The amounts of requests for the non-guestroom areas ranged between 6.9 per day (October) and 11.3 per day (July). In terms of proportion, the variation in the maintenance requests for the non-guestroom areas was even greater than that for the guestrooms.

'Insert Figure 3 here'

In this study, the interval between the start time and the completion time of a work order, which measures the time taken to clear a maintenance request, was taken as the downtime of the concerned equipment. Such equipment downtime, rather than being the time when the room is "down", is the duration during which the equipment could not function properly. For example, the malfunctioning of a power socket in a guestroom does not necessarily mean the whole guestroom is not habitable. While the amount of time a guestroom was out of service due to maintenance works is of importance to this highly occupied hotel, this kind of room downtime was out of the scope of data that the CMMS was set to consistently record.

The mean daily total equipment downtime for each month, which may be taken as a maintenance performance indicator, was determined by summing the downtimes ascertained from all trades of work orders in the month, followed by dividing the sum by the number of days in the month. Because there were four work trades each covering multiple equipments which required maintenance, the monthly mean daily total downtime values calculated by this method could exceed 24 hours. But as shown in Figure 4, which was prepared by plotting the monthly equipment downtime per day against number of requests per day, no such case had happened in the guestrooms or the non-guestroom areas.

Nevertheless, the scatter plot in Figure 4 makes it apparent that the maintenance workload due to the guestrooms, either in terms of volume of request or amount of downtime, was well above that due to the non-guestroom areas. A strongly positive correlation can also be seen in both cases: the larger the amount of maintenance requests, the longer the equipment downtime. This implies that some maintenance works could have been interrupted by new and more urgent requests before they could be completed.

'Insert Figure 4 here'

The amounts of work order and equipment downtime pertaining to different trades of work were analyzed further by compiling the relevant statistics, including their mean, minimum and maximum values, and standard deviation (*SD*) and coefficient of variation (C_v). The results summarized in Table 2 show that the highest mean monthly number of orders was for works in the EL trade and the lowest in the AC trade. The same observations were noted for the mean monthly equipment downtime values.

'Insert Table 2 here'

As to the C_v values, the highest ones belonged to the AC trade, both for the number of work orders and the amount of equipment downtime. In contrast, the lowest values were with the EL trade. These findings indicate that the workloads of the AC maintenance works were the most variable whereas those of the EL works were the least variable.

The monthly room occupancy rate of the hotel ranged from 76.8% to 93.5%, and the mean of the monthly rates over the entire studied period was 87.3%. Suspecting that the number of guests staying in the hotel may affect the amount of maintenance requests and equipment downtime, a series of correlation analyses was carried out based on the monthly values of these variables, where the room occupancy rate was taken as a proxy for the number of guests in the hotel. A moderately positive correlation was found to exist between the occupancy rate and (i) the amount of work orders (r = 0.648); and (ii) the amount of downtime (r = 0.598). The correlation between the amount of work orders and downtime was more significant (r = 0.873), which concurs with the findings shown in Figure 4.

Further examinations were made on the same set of variables but refined to individual work trade level. The computed correlation coefficients are consolidated in matrix form, as shown in Table 3. From these results, highly positive correlations between the amount of work orders and downtime across all the work trades (r = 0.757 to 0.887) were noted. Except that a weak correlation (r = 0.229) was found between occupancy rate and amount of AC work orders, moderate correlations (r = 0.356 to 0.690) were observed from the remaining results.

'Insert Table 3 here'

3.2 *Maintenance Manpower*

According to the organization chart of the maintenance team (Figure 1), the total headcount of technicians was 17, which comprised four AC technicians, four electricians, four plumbers and five BW technicians. Whereas this total headcount represents the manpower establishment for maintenance works in the hotel, an inspection of the duty schedules of the technicians unveiled that the actual manpower available was variable within the studied period, for reasons that include: technicians were on vacation or sick leaves; some technicians had resigned and left but their replacements were pending; and so on. For quantifying the actual manpower available for undertaking maintenance works, the number of technicians who were on duty and their duty durations in the four shifts of each day were counted. The sums of these durations, in number of man-hours per month, were calculated for the four trades and as shown in Figure 5.

'Insert Figure 5 here'

Different from the manpower of the BW trade which stayed at a rather steady level, the AC manpower varied significantly throughout the year. The particularly low manpower levels in July and December were due to departure of two AC technicians. The EL trade also exhibited drops in manpower level in January and February during which only three of the four electrician posts were filled. Whereas the manpower level of the PD trade seemed to be stable for most of the time, there was a full team of plumbers only in January.

The productivity of the maintenance technicians was assessed by using the work efficiency (E) depicted by Equation (2), where N_O is number of work orders completed and H_U the amount of man-hours used. Two separate sets of monthly work efficiency values were determined based on the completed work orders and the used man-hours in each month for the guestroom and non-guestroom areas.

$$E = \frac{N_O}{H_U} \qquad (2)$$

As shown in Figure 6, the efficiencies of maintenance works for the guestrooms, which ranged between 2.72 and 3.19 orders completed per man-hour, were fairly steady over the year, and were generally higher than those for the non-guestroom areas (range: 1.71 to 2.74 orders completed per man-hour). The factors contributing to this observation include that guests would not tolerate prolonged maintenance works in their rooms and that maintenance works for guestrooms would comprise a greater portion of relatively minor works but maintenance works in the non-guestroom areas could involve more complicated central engineering system equipments and components.

'Insert Figure 6 here'

From January to August, the variation patterns of the guestroom and non-guestroom work efficiencies were similar. The non-guestroom work efficiency appeared to rise substantially from August to almost the same level of the guestroom counterpart in December. This observation may be due to the comparatively small amounts of work orders in the non-guestroom areas (Table 1) that resulted in significant variations in the efficiencies of the works there over the twelve months studied.

Using Equation (2) again, the monthly work efficiencies of the four work trades were separately calculated and statistically analyzed. The mean, minimum, maximum, *SD* and C_v values so obtained are shown in Table 4. This set of results shows that the mean efficiency of EL works was the highest, followed by that of PD, BW and AC. Although the AC works were on average the least efficient, the lowest and the largest efficiency levels, as well as the largest *SD* and C_v values, all belong to the AC trade, which corroborates that AC works were the most variable. In contrast, variations in the efficiency of the EL trade were the smallest. It was further identified that the incandescent lamps, which as mentioned earlier were the main type of illumination for the hotel, gave rise to 3,450 work orders (i.e. 19.4% of the total). While this is a significant factor for the largest share of the electrical orders (see Table 1), the fact that faulty incandescent lamps can be readily replaced should have contributed to the highest and least variable efficiency of the EL trade.

'Insert Table 4 here'

To provide a measure of whether there was sufficient manpower to cope with the demand for maintenance works, the monthly levels of utilization (*U*) of manpower deployed in each of the four trades the works recorded by the CMMS was calculated using Equation (3), where H_U is the man-hours used and H_A the man-hours available for work execution.

$$U = \frac{H_U}{H_A} \quad (3)$$

As the statistics of the calculated results show (Table 5), the mean utilization levels were low, ranging between 8.8% and 36.4%. The average value over the four trades was close to 20%, which matches with the rule of thumb for the amount of corrective maintenance works. Furthermore, the maximum utilization levels of the four trades were between 16.4% and 56.0% only. These relatively low utilization levels were due to the fact that besides performing the corrective maintenance works recorded by the CMMS, the technicians had to carry out some other works like regular inspections and preventive maintenance works.

Paying more effort in preventive maintenance should be able to reduce the demand for corrective maintenance (Lai et al., 2009). If data of the preventive maintenance works were made available, the manpower utilization levels based on the amount of time used for performing both corrective maintenance and preventive maintenance could be determined. Further analysis could also be made to examine the relationship between the preventive maintenance effort and the resources spent on corrective maintenance, such as the cost for such work and the associated staffing level.

As long as the works recorded by the CMMS are concerned, the electricians, as compared to the technicians of the other trades, were on average utilized at the highest level (36.4%), which is more than four times the mean utilization level of the AC technicians. On average, the AC technicians were utilized the least and the minimum level of utilization of this trade was as low as 4.7%. On the other hand, the highest C_v value of the AC trade tells that its manpower utilization levels varied the most.

‘Insert Table 5 here’

3.3 *Work Performance*

The findings on work efficiencies (Figure 6) imply that equipment downtimes in the guestrooms should be shorter than those outside the guestrooms. This deduction was verified by examining the distribution of downtimes in these two areas. As depicted in Figure 7, the cumulative proportion curve of the guestrooms is clearly above that of the non-guestroom areas. Based on the *Pareto* rule, 80% of the maintenance requests in the guestrooms were resolved within 30 minutes but the same proportion of requests in the non-guestroom areas required 10 more minutes to settle.

'Insert Figure 7 here'

In principle, evening out the marginal outputs of different factors of production would allow efficiency to be optimized but, in the present case, account should be taken of the differences in complexity of the maintenance works in different areas and in different work trades. Nonetheless, the benchmarking curves (Figure 7) are useful performance evaluation tools for the hotel. In striving for continuous improvement of the maintenance services, more stringent downtime limits, e.g. downtimes smaller than 30 minutes and 40 minutes for the guestroom and non-guestroom areas respectively, may be set as the performance targets for the maintenance works in future. But in this connection, caution should be taken to ensure that a more speedy maintenance work should not be achieved at the expense of work quality.

More in-depth investigation was made into the distribution of equipment downtimes with respect to the four trades, by plotting the number of requests against the downtimes in each trade. As shown in Figure 8, magnitudes aside, the four distribution patterns are similar in that the majority of orders in the four trades were completed between 5 to 15 minutes.

‘Insert Figure 8 here’

According to the information collected from the hotel, a range of time limits for work completion, as summarised in Table 6, had been preset for some critical maintenance works, where some corresponding examples of maintenance problems are also given. Common to the AC, EL and PD trades, the shortest time limit was 30 minutes. Whereas the shortest time limit for the BW trade was 20 minutes, such a limit was set for problems such as loosened entrance door handles, which should be fixed the soonest possible to maintain the security of the concerned guestroom. The most relaxed time limit was 180 minutes, which is for works like repair of a cracked wash basin. In this example, the allowance is not lax at all given that the repair work typically involves some wet work which takes time to dry up or even replacement of the cracked basin with a new one.

‘Insert Table 6 here’

The reasonableness of the preset time limits was evaluated by an analysis of the completion status of the work orders. The results, as summarised in Table 7, reveal that the majority of work orders in the four trades were completed on time. The best performer in this sense was the EL trade, whereas the highest proportion of orders completed beyond the time limits was pertaining to the AC trade, followed by BW and PD.

‘Insert Table 7 here’

A rather small proportion of the orders was remarked as ‘cancelled’ or ‘time out’. The former group covered two main types of requests, including those that were raised by the end-users but required no maintenance works to settle (e.g. room air was reported as too cold by a guest who did not know how to tune the room thermostat), and those that could only be fixed some days later due to their specific nature or other constraints (e.g. the required spare part for replacing a faulty component was out of stock). As to those grouped under ‘time out’, they were recorded when the technicians failed to complete the orders even beyond the extra time authorised by the relevant Duty Engineer, or when the necessary time extensions were not keyed in to the CMMS before reaching the original time limits.

4. Conclusions

Based on a typical quality hotel in Hong Kong, this study has unveiled the operations of the CMMS and the procedures and parties involved in recording and executing the maintenance works for the engineering facilities in the hotel. Overall, the maintenance requests were dominated by requests for works on electrical installations. The maintenance workload from the guestrooms, as measured by the work orders issued, far outweighed that from the non-guestroom areas. For both of these areas, a highly significant correlation between the mean daily equipment downtime and work orders issued was observed in all the four work trades, i.e. air-conditioning, electrical, plumbing and drainage, and builder’s work.

The monthly variations in available maintenance manpower in the four work trades, the levels of their utilization, and the work efficiencies of the technicians were investigated. The results yielded by statistical analysis on these parameters, including their mean, minimum and maximum values, can serve as benchmarks for gauging future performance of the same hotel, or for making comparisons with similar hotels. For a more comprehensive analysis of manpower utilization, it is essential to record the man-hours devoted to preventive maintenance works in addition to those for corrective maintenance.

Equipment downtimes, which indicate the speediness and hence the performances of the maintenance works, were scrutinised between different areas and different work trades. The cumulative proportion curves, as shown in Figure 7, can be used for evaluating the celerity of the maintenance works or for setting higher performance targets for the works. Whereas the collected data enabled the identification of equipment downtimes, the durations during which the guestrooms are "down" (i.e. out of service) due to maintenance issues are needed in order to assess the overall maintenance performance of the hotel. It is, therefore, recommended that the CMMS should be enhanced by incorporating appropriate capabilities for recording such room downtimes as well as analysing the various performance measures that have been reported above.

While this study has piloted to demonstrate how the maintenance works of hotel engineering facilities may be evaluated with respect to workload, input manpower and performance outcome, further studies of this kind are needed before the findings can be generalised for adoption across the hospitality industry. When more benchmarks are made available, hotel managers would be better able to tell how well the maintenance works for their facilities are being delivered and where the room for improvement lies.

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List of Tables

Table 1 Summary of work orders issued

Trade	Total No.	Guestroom		Non-Guestroom	
		No.	%	No.	%
Air-conditioning	1223	771	63.0	452	37.0
Electrical	8896	7404	83.2	1492	16.8
Plumbing & drainage	4428	4121	93.1	307	6.9
Builder's work	2921	2276	77.9	645	22.1
Unclassified	331	0	0.0	331	100.0

Table 2 Statistics of monthly work orders and equipment downtimes

	Air-conditioning		Electrical		Plumbing & drainage		Builder's work	
	WO	DT	WO	DT	WO	DT	WO	DT
Mean	107	2815	775	15200	389	8482	256	5991
Min.	73	1525	654	13439	297	6522	202	4071
Max.	162	4967	911	17419	515	12603	317	9179
SD	28	1034	88	1262	65	1760	38	1776
C_v	26.3	36.7	11.3	8.3	16.7	20.7	14.7	29.6

DT: downtime (in minutes); WO: work order (in No.).

Table 3 Correlation coefficient (*r*) matrices of different work trades

	Air-conditioning		
	Occupancy rate	Work order	Downtime
Occupancy rate	1	-	-
Work order	0.229	1	-
Downtime	0.410	0.792	1
	Electrical		
	Occupancy rate	Work order	Downtime
Occupancy rate	1	-	-
Work order	0.539	1	-
Downtime	0.506	0.851	1
	Plumbing & drainage		
	Occupancy rate	Work order	Downtime
Occupancy rate	1	-	-
Work order	0.690	1	-
Downtime	0.620	0.887	1
	Builder's work		
	Occupancy rate	Work order	Downtime
Occupancy rate	1	-	-
Work order	0.370	1	-
Downtime	0.356	0.757	1

Table 4 Statistics of work efficiencies of different trades

Trade	Mean	Min.	Max.	*SD*	C_v
Air-conditioning	2.40	1.86	3.45	0.54	22.4
Electrical	3.06	2.71	3.33	0.19	6.1
Plumbing & drainage	2.77	2.36	3.34	0.25	9.1
Builder's work	2.67	1.87	3.20	0.45	17.0

Table 5 Statistics of utilization levels of different trades

Trade	Mean	Min.	Max.	*SD*	C_v
Air-conditioning	8.8%	4.7%	21.6%	4.3%	49.2
Electrical	36.4%	20.1%	56.0%	8.7%	23.8
Plumbing & drainage	22.7%	16.1%	31.7%	4.1%	18.0
Builder's work	10.0%	7.0%	16.4%	3.1%	30.8

Table 6 Time limits for fixing maintenance problems

Trade	Time limits (minutes)	Example of problem
Air-conditioning	30	Room air too cold
	45	Water dripping from air-conditioning unit
	60	Air-conditioning unit too noisy
Electrical	30	Lamp next to entrance door burnt
	45	No electrical supply to socket
	60	Lamp inside wardrobe burnt
	90	Fail to dim bedhead lamp
Plumbing & drainage	30	Water leakage from WC cistern
	45	Blockage of WC
	180	Cracked wash basin
Builder's work	20	Loosened entrance door handle
	30	Fail to open/close desk drawer
	40	Fail to open/close TV cabinet
	60	Loosened ceiling panel

Table 7 Summary of completion status of work orders

Trade	On time	Late	Cancelled	Time out
Air-conditioning	75.7%	20.1%	2.5%	1.6%
Electrical	85.1%	13.4%	1.0%	0.4%
Plumbing & drainage	84.4%	13.6%	1.4%	0.6%
Builder’s work	79.6%	17.8%	1.3%	1.2%

List of Figures

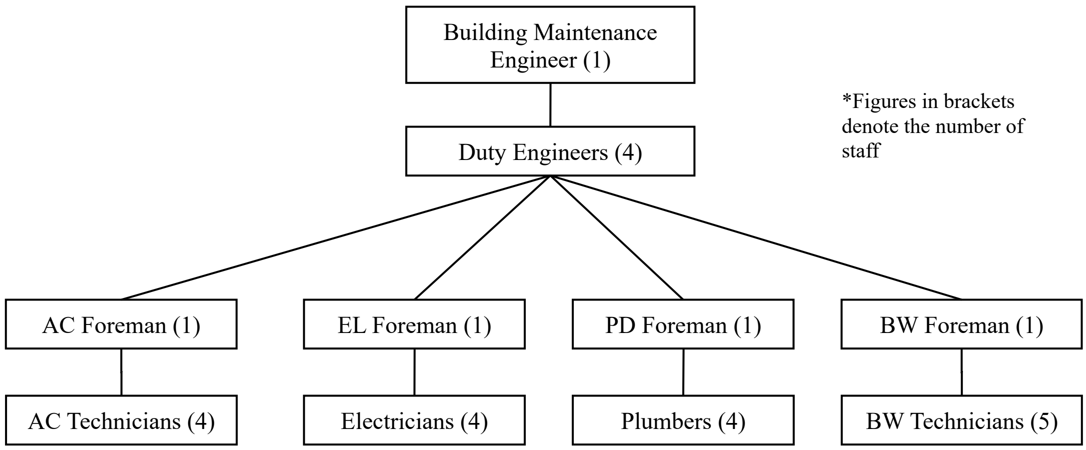

Figure 1 Organization of the maintenance engineers, foremen and technicians

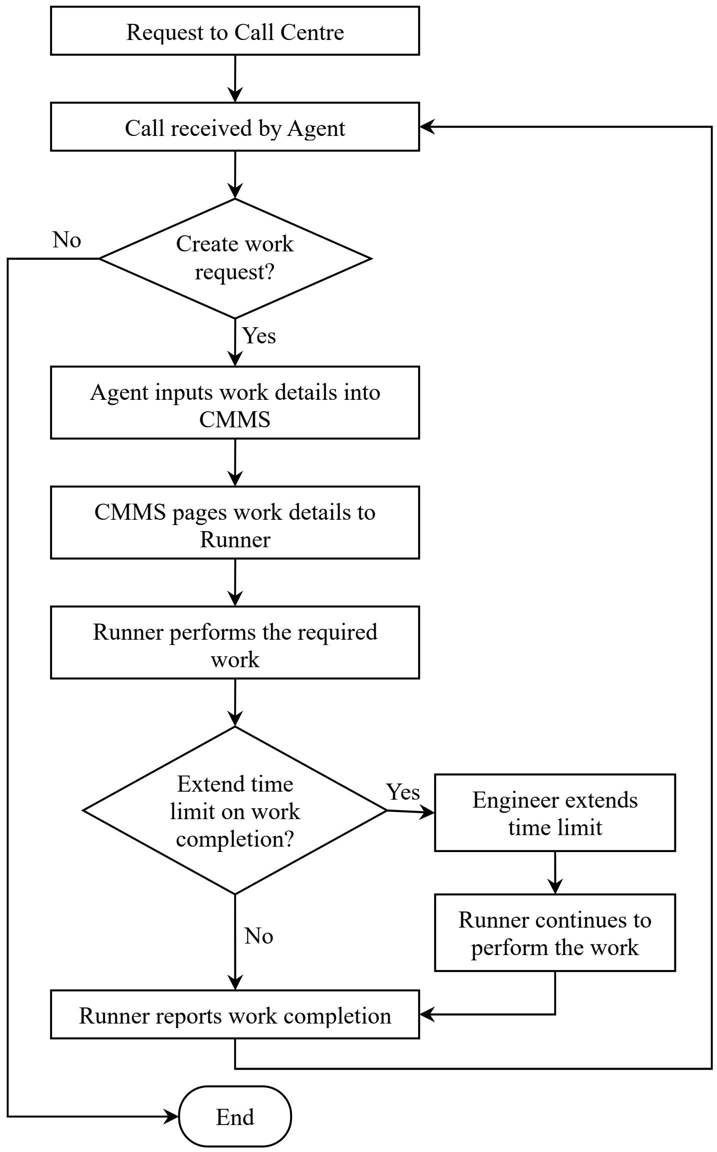

Figure 2 Work Flow of the CMMS

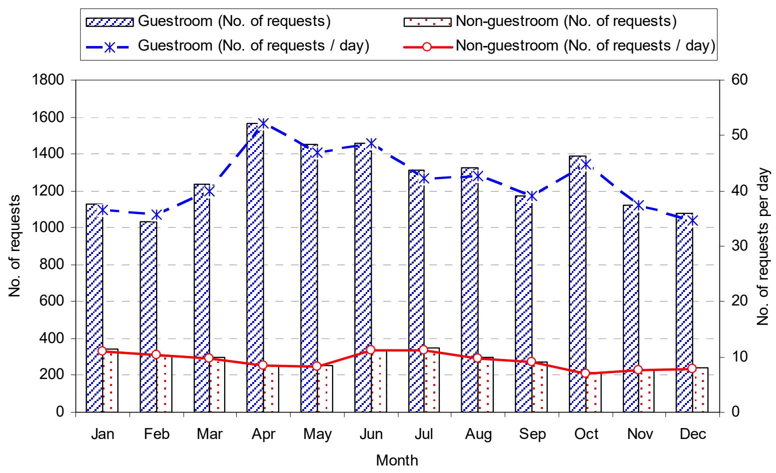

Figure 3 Monthly amounts of maintenance requests

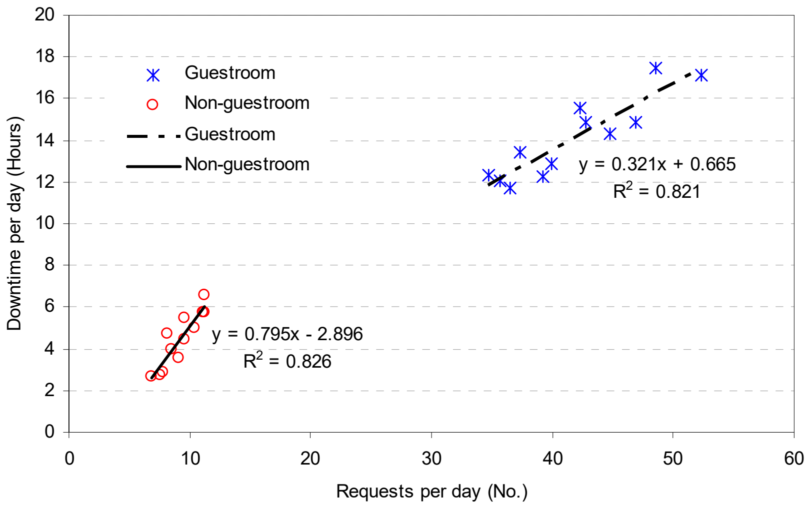

Figure 4 Relation between maintenance request and equipment downtime

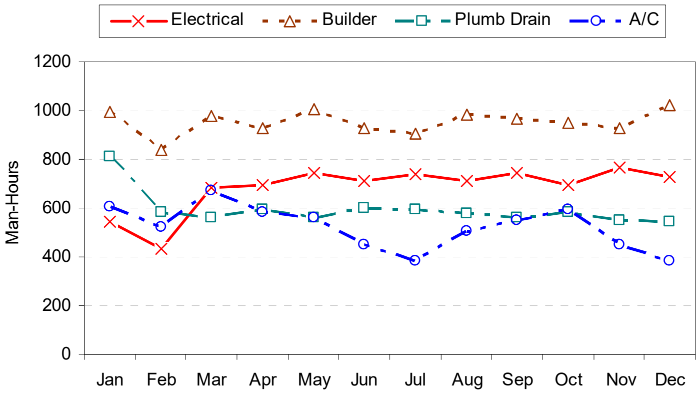

Figure 5 Monthly available man-hours

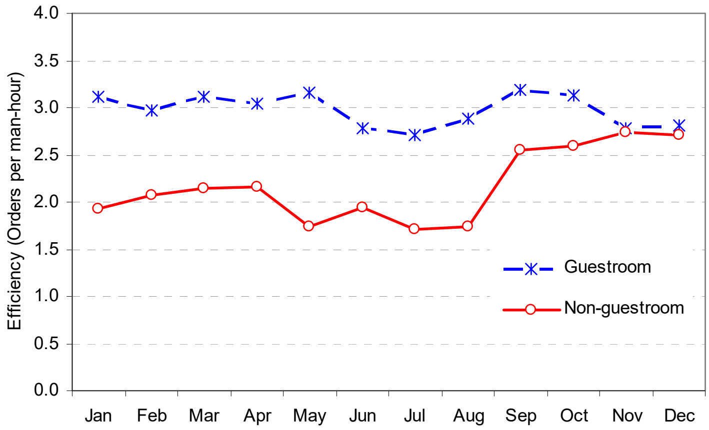

Figure 6 Monthly variations of work efficiencies

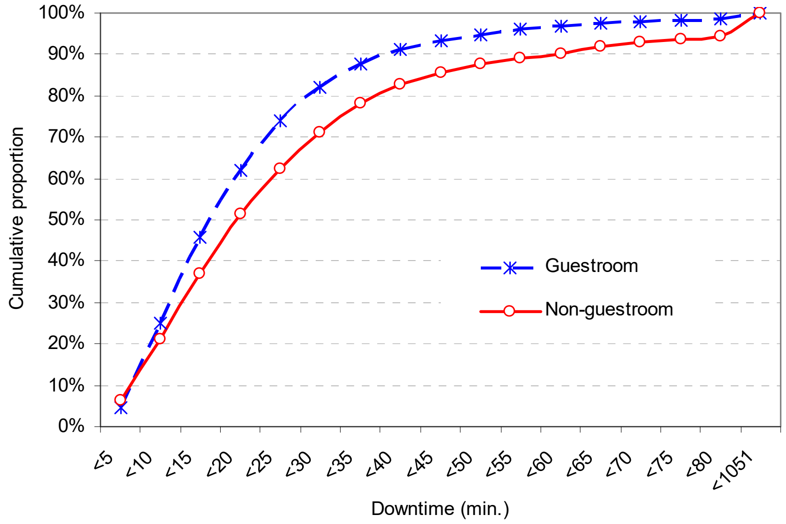

Figure 7 Cumulative proportions of equipment downtimes (by areas)

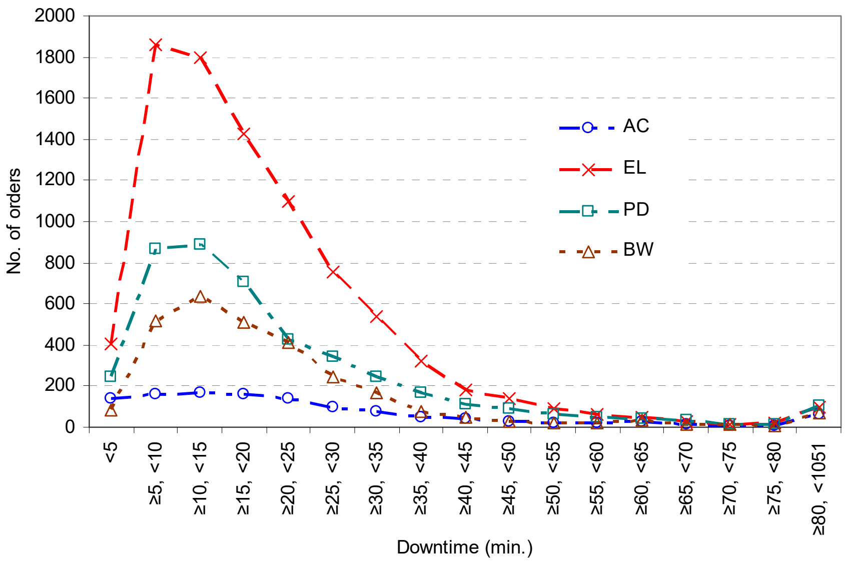

Figure 8 Distribution of equipment downtimes (by trades)