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A Probe into the Facilities Maintenance Data of a Hotel

(Short title as running head: "**Hotel Facilities Maintenance**")

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Abstract:

The performances of facilities in buildings have profound influence on the end-users' satisfaction. This, in turn, would affect the income of buildings and hence the level of resources available for maintaining the facilities. Probing into the computerized maintenance management data of a quality hotel, the study reported here identified a strongly positive correlation between the facilities' downtime and the quantity of maintenance work orders. Rather than productivity, work efficiency, which declined with increasing utilization levels of the workers, was found to be a more exact measure for the effectiveness of workforce. Scrutinising the utilization and efficiency levels of workers enabled a review of their workloads and performances. Establishing benchmarking curves based on facilities' downtime, as illustrated, can help improve the quality of maintenance works. Further research works are needed to study the effects of low and moderate occupancy rates on maintenance demand, the utilization and efficiency levels of workers in performing preventive maintenance works, and the availabilities of unreliable facilities and those which are hard to maintain.

Practical application:

It has been shown how the data stored in a computerized maintenance management system can be analysed to examine the demand for facilities maintenance, the effectiveness of a maintenance workforce and the performances of facilities. The reported approach and results are useful for facilities management (FM) practitioners. Findings from more studies of this kind would make further contributions in performance evaluation and benchmarking in the FM field.

1. Introduction

The expectation of end-users on the performances of facilities in buildings has been rising. Hotel customers, in particular, demand a very high service level. Other than soft services like concierge and housekeeping, the performances of hard services including upkeep of builder's works (e.g. building fabric, grounds, furniture) and maintenance of building services (e.g. electrical, air-conditioning and fire protection installations) have profound influence on the customers' satisfaction. This, in turn, would affect the hotels' income and hence the level of maintenance resources available.

Among the resources input for producing maintenance works, the cost for manpower is substantial[1]. Optimization of this cost element, therefore, has been a common interest of many hoteliers. Meanwhile, it is imperative to ensure that the available manpower is effectively utilized, without which the celerity and quality of maintenance works could hardly be satisfactory.

Unlike ordinary commercial buildings in which the maintenance data are often logged manually[2], maintenance requests in hotels need to be recorded promptly so that swift actions can be taken to rectify the malfunctioned facilities. For this purpose, computerized maintenance management systems (CMMS) have been increasingly used in hotels, especially those with a high quality. Nevertheless, the data recorded in such systems, e.g. number of faults, repair time etc., are usually regarded as sensitive and thus restricted from access. Studies on this area, therefore, had been scarce.

Whereas the general lack of research on the impact of computerized technology on the qualitative aspects of hotel performance had been identified long ago[3], a recent search from the open literature could only find a paucity of study findings which are focussed on the maintenance performance of hotels. For instance, Chan *et al.*[4] attempted to develop some performance indicators for measuring the effectiveness of maintenance for hospitality engineering systems.

In other regimes such as the industrial sector, maintenance matters have been widely studied. Apart from mainstream maintenance textbooks and handbooks, e.g. Stephens[5], Dhillon[6] and Palmer[7], there are lots of journal publications on maintenance for industrial facilities like manufacturing and production plants. Some examples include: the development of a structured maintenance management tool[8]; a review and analysis of the applications of maintenance optimization models[9]; some experiences on maintenance performance reporting systems[10]; and the search for a maintenance productivity index for measuring maintenance performance[11]. Furthermore, adoption of the ARM approach (i.e. measurement and management of availability (A), reliability (R) and maintainability (M)) has been common in the industrial sector, particularly in the heavy industries like defence and aerospace where proper functioning of their systems and equipments is of supreme criticality.

In the sector of building services engineering, maintenance guidebooks are available (e.g. Smith and Tate[12]; Armstrong and Saville[13]). Empirical cost studies on building services maintenance (e.g. Lai *et al.*[14]) have emerged. Implementation of the ARM approach has also been advocated for identifying appropriate maintenance strategies for services systems and equipments in buildings[15]. In reality, however, data about the relevant parameters are seldom captured. Typical reasons include the lack of resolve or knowledge for capturing the data[16].

Apart from some statistical prediction studies on the quality of building services systems (e.g. Loy *et al.*[17]), in-depth investigations into the real maintenance data of facilities in buildings are yet to be seen.

In order to explore broader and deeper into the area of facilities maintenance in buildings, a study was carried out to probe into the maintenance data of a hotel in Hong Kong. Aimed at investigating the maintenance demand, manpower input and outcome performance of its facilities, the data recorded by the CMMS of the hotel were collected and analysed.

The first part in the following reports on the process of data collection, the various kinds of data collected, and the measures taken for ensuring the quality of the data. Described in the next part includes the characteristics of the hotel's facilities, the organization of its maintenance workforce, and the practice of recording and executing its maintenance works. In the subsequent part, the analyses on maintenance demand, effectiveness of maintenance workforce and maintenance performance are reported. The conclusions drawn and the further works needed are consolidated in the final part.

2. Data collection

The data collection process commenced from a meeting with the hotel's Director of Engineering and two of his colleagues - one having worked long in the hotel and the other responsible for overseeing the CMMS. The discussions made at this meeting were on three aspects: i) characteristics of the facilities in the hotel; ii) the practice of its operation and maintenance works; and iii) the operation of the CMMS.

Further to the factsheets of the hotel, which inform its gross floor area, number of storeys, types and quantities of guestrooms and other major function areas, etc., information about the plant capacities and schematic diagrams of the major trades of building services such as electrical, air-conditioning, and plumbing and drainage installations were also collected. To help visualize the nature and scale of these facilities, a walk-through around the main areas and plant rooms was paid after the meeting.

For understanding their operation and maintenance practice, the staff members were requested to brief on the organization of the engineering department, the categorization for their maintenance works and the roles and functions of the relevant staff, and the work processes and procedures. The study team was also given the opportunity to appraise the operation of the CMMS by visiting the Service Centre where the main terminal of the system was located. During this visit, the staff members explained how the maintenance requests were handled, including who would take which of the required actions.

Four kinds of record information over a period of 12 months were collected. The first kind was an annual report on the statistics of services requests. This report was generated by the CMMS, summarising the number of maintenance requests for every single job item (e.g. blockage of water closet, lamp burnt, etc.) handled by the engineering department. Another kind of information, also generated by the CMMS, was called Detail Listing of Service Request Report. It contains a long and complete list of all the maintenance orders over the studied period, and the information displayed includes date, start time, finish time, time duration of work completed beyond the prescribed time limit, location of work, work description, and identities of the responsible service agent (i.e. CMMS operator) and service runner (i.e. technician).

Depending on the nature and criticality of the failures, some time limits were set for completing the necessary works for their resolutions. A file showing these prescribed limits was the third kind of information collected. The final kind of information was the duty schedules of all the maintenance technicians. These schedules show which of the technicians were on duty or on leave during the three different shifts in a day (9 hours per shift including one hour for taking meal). These two kinds of information, as will be analysed later, are essential for evaluating the promptness of maintenance works and the utilization of manpower.

3. The Hotel and its Maintenance Works

The studied hotel, being one among its international chain, was a 33-year-old 4-star hotel. With a gross floor area of over 40,000 m^2, it was 19-storey high, accommodating 618 guest rooms of which 298 were single-bedded, 316 were double-bedded and four were suites. The aggregate areas of the function rooms, food and beverage outlets and kitchens were 1,657 m^2, 2,041 m^2 and 355 m^2 respectively. All the guestrooms, furnished with quality builder's works (fabric and finishes), were provided with electricity, air-conditioning, fire services, cold and hot water supply, and drainage installations. Table 1 summarizes the key provisions inside these rooms.

Headed by the Director of Engineering, the total headcount in the engineering department was 31 (Figure 1). Besides an Assistant Director and a Project Engineer who handled relatively large-scale improvement and renovation projects, another Assistant Director, assisted by Building Maintenance Engineer, was responsible for managing the engineering team who took care of all preventive and corrective maintenance works except those statutory works (e.g. annual inspection of fire services installations) that must be undertaken by registered contractors[18]. Given the round-the-clock operation of the hotel, the operational staffs of this team, including those at the foreman level and below, were supervised by four Duty Engineers who worked on shifts. According to their specialist skills, they were grouped into four different trades, namely air-conditioning (AC), electrical (EL), plumbing & drainage (PD) and builder's work (BW).

Malfunctioning of equipments will be noticed if they are in use. But if they are left idle (standby), their malfunctioning would not be discovered until they are called to operate or when they are inspected. Major equipments in the central plants such as chillers, pumps and main switches were provided with standby units or spare capacities. Their failures, according to the maintenance staff, were infrequent and so were manually recorded in logbooks. But the maintenance requests for the numerous facilities in the guestrooms and function areas, in order to meet the demanding end-user needs, were recorded by the CMMS to allow tracking of their status online.

As Figure 2 depicts, a maintenance request starts from a malfunctioning which may be found occasionally by a guest or a housekeeper, or during a regular inspection by a technical staff. The request will be reported by phone to the Front Office or Housekeeping Section which, in turn, will relay it to the Guest Service Centre (GSC) for recording in the CMMS. For prompt input of the request into the CMMS, descriptions for the common malfunctions were predefined.

The CMMS, taking into account the trade of work required and the availability of the respective technicians, would issue a work order by sending out a short message service (SMS) to the mobile phone of the most available technician. Upon receiving the SMS, the technician will need to acknowledge it, go to the scene, and tackle the problem. If the maintenance work required for resolving the problem is minor and can be done readily by the technician, the request would be settled right away. But if the work entails some tools or materials that are not normally equipped with the technician, he will need to travel back and forth to the workshop to get the tools/materials needed. In any case, the technician would report to the GSC upon completion of the maintenance work.

Given the high end-user expectation, whenever the maintenance request could not be settled timely, repeated requests or even complaints would be lodged by the users. Meanwhile, the request will be escalated to personnel at the higher levels of the maintenance department. For instance, when a technician could not fix a maintenance problem within the prescribed time limit, his foreman will be prompted. When the problem remains after the allowed additional time, the duty engineer will be alerted, so on and so forth. Table 2 summarizes the repair time limits that had been set for some particular job items.

Referring to the sequence of maintenance work in Figure 2, there are various time durations associated with the episodes of a work order, which are as shown in Table 3. For assessing the promptness of maintenance works, time durations T_2 to T_7 are relevant. As the hotel staff advised, the total duration of T_2 and T_3 is very short, and thus negligible. The sum of the remaining time durations, i.e. T_4 to T_7, was recorded by the CMMS and was taken as downtime of the malfunctioned facilities.

4. Analysis and Discussions

4.1 Maintenance Demand

As recorded in the original report on the statistics of services requests, the annual total count of items with different job descriptions was 761. The dominant trade was EL, followed by PD and BW, both of which being comparable (Table 4). The AC trade recorded the minimum number of non-identical job items.

To ensure that these recorded data are of good quality for analysis purpose, a detailed checking was made on each of the job items, which found that some were classified into a wrong trade. After making the corrections, EL remained as the trade containing the largest number of job items which are different. But instead of PD, BW became the second dominant trade. The description of one job item was found to be unclear and so could not be classified.

A huge number of work orders, 17,799, were issued. Inspection over all these orders, though extremely time-consuming, discovered that 1.86% of them were unclassified (UC) for reasons such as their descriptions were missing or unclear. Overall, half of the orders belonged to the EL trade. The portion of PD orders was about one-fourth, and the sum of those under the BW and AC trades contributed to almost the same share.

The amounts of maintenance requests for each of the 12 months were counted and then plotted in Figure 3. With the exception of the demand in June, the monthly demands, which ranged between 1319 in December and 1824 in April, appeared to be fairly steady. In view of the exceptionally low demand (1000) in June, a checking was made on the whole set of collected data, which resulted in detecting the missing of data record between two periods: 18 - 30 June and 29 - 30 September. Upon clarification with the hotel staff, this was due to the breakdowns of the CMMS.

For addressing this problem and considering the varied numbers of days per month (e.g. in 2008 there were 31 days in January and 29 days in February), the number of work orders in each month was divided by the number of days in the respective month to yield the number of work orders per day, which allows comparing the monthly demands on the same normalized basis. With a mean demand of 51.0 work orders per day (minimum: 42.5; maximum: 60.8), the calculated results are displayed in Figure 3. Their variations, when compared to those in the preceding part, were less fluctuating.

In order to investigate if any relationship existed between the quantity of work orders and the amount of downtime of the facilities, Figure 4 was constructed by plotting the recorded data of the latter against those of the former. It shows a strongly positive correlation – the larger the number of requests, the bigger the downtime.

It was anticipated that a higher occupancy rate, i.e. a higher number of hotel guests, would lead to a higher number of maintenance requests, and so a bigger amount of facilities' downtime. Therefore, a scatter plot of the data of these two parameters against occupancy rate is made, as shown in Figure 5. It is noted, however, that only weak correlations existed although the volumes of requests and downtime gently increased with the occupancy rate. Whether the same observation would take place at lower occupancy rates is yet to be investigated given that the studied occupancy rates, which ranged between 76.8% and 93.5% (average being 87.3%), were relatively high.

4.2 Effectiveness of maintenance workforce

The investigations reported so far cover only the volumes of maintenance demand, their monthly variations, and the influence of occupancy rate on maintenance demand. Whether or how effectively the maintenance demand was met is to be uncovered. For this purpose, it is necessary to study the utilization effectiveness of the corrective maintenance resources, among which the deployed manpower predominates[19].

A parameter that has been widely used for measuring the effectiveness of a workforce is productivity (P), which is commonly defined by Equation (1), where N_O is the number of work orders completed within the observed period and N_W is the number of workers deployed.

$$P = \frac{N_O}{N_W} \tag{1}$$

Another parameter that can be used for measuring productivity in a closer manner is efficiency (E) of workers. It can be obtained by dividing the number of work orders completed (N_O) by the amount of man-hours used (H_U), i.e. Equation (2).

$$E = \frac{N_O}{H_U} \tag{2}$$

Since productivity and efficiency may depend on the amount of manpower available as well as the extent to which the amount of manpower is used for carrying out the works, it is essential that the utilization (U) of manpower, which is defined as the ratio between the man-hours used for work execution (H_U) and the man-hours available for undertaking works (H_A), is also investigated. It can be calculated by Equation (3).

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

The manpower available was figured out by referring to the monthly duty schedules of the technicians. It was found that the headcounts of technicians indicated in the organization chart (Figure 1) represent the maximum numbers of technicians that would be employed. In fact, some posts were vacant during parts of the studied period, for reasons such as some technicians had resigned while their replacements were pending. The number of workers pertaining to a particular trade in a month was determined by counting the number of technicians that had ever reported duty in that month. The headcounts so obtained were taken for computing the mean, minimum and maximum values, which are summarized in Table 5. Also shown in this table are the amounts of available man-hours, which were found by counting the numbers of technicians who were on duty while discounting the absent manpower (e.g. vacation leaves, sick leaves) in each shift of every day.

The statistics of monthly work orders and downtimes in respect of the four different trades are shown in Table 6. Note that in drawing these statistics, the missing amounts of work orders and equipment downtimes in June and September (due to the CMMS breakdowns) were taken to be in proportionate to the recorded counterparts in the corresponding months. The largest monthly mean values in the volumes of work orders and downtime were found with the EL trade. Whereas the smallest values belonged to the AC trade, the highest coefficients of variation (C_v) of this trade indicate that its work orders were the most variable, both in terms of number of work orders and amount of downtime.

The above-determined headcounts, together with the numbers of work orders completed, make it feasible to calculate the workers' productivity (Equation 1). But the productivity obtained in this way is imprecise given the varying numbers of workers during some of the months. For overcoming this problem, the worker's efficiency was computed (Equation 2) based on the actual amount of man-hours used in each of the months instead of the approximate headcounts over the same period.

Figure 6 shows the above computed results, namely productivity and efficiency. The former appeared to be fluctuating but the latter, which was determined by the more accurate method, was highly steady (minimum: 2.49; maximum: 3.08). Shown in the same figure are the levels of manpower utilization, which were calculated using Equation (3). With the lowest utilization level being 16.4% (in September), the peak level (25.0%) occurred in both June and July. Deduced on the basis of this level, the maximum proportion of manpower that can be deployed for handling works other corrective maintenance, e.g. preventive maintenance work, monitoring of outsourced maintenance work, maintenance-related administration work, etc. is 75% of the available manpower.

In theory, a higher efficiency is obtainable through mass production, i.e. utilizing more of the available manpower to produce a larger volume of work of the same kind. On the other hand, the efficiency of workers would drop when they become exhausted at an exceedingly high level of utilization. The finding in Figure 7, which shows that the workers' efficiency was negatively correlated with their utilization level, supports the latter principle. Note that the observed utilization levels were rather low (below 25%), which may be due to the fact that the workers had to carry out some other works (e.g. preventive maintenance) in addition to the corrective maintenance works.

The work efficiency was differentiated with respect to different trades of work. This was done by plotting the monthly work efficiencies of the four trades on Figure 8. Basically, no apparent observation is noted except that in line with the large variations in worker order quantity and downtime (Table 6), the largest range of efficiencies occurred in the AC trade. This may be attributed to the uneven completion times of the AC maintenance works, which are inherited from their varied complexities.

On the contrary, the range of the work efficiencies of the EL trade was the smallest, showing that the amounts of work orders completed per unit man-hour were rather stable. The remaining two trades, i.e. PD and BW, exhibited moderate variations in their workers' efficiencies.

Unlike the results on efficiency, distinct differences were found between the utilization levels of the different trades of work (Figure 9). Utilization of the technicians of the EL trade was clearly higher than that of the remaining trades. The peak level, as high as 56.0%, occurred in February when one of the four electricians resigned. The variations in the utilization of the AC and BW technicians were highly similar and, when compared with the utilization level of the EL technicians, their utilization levels were rather low.

The highest utilization level of the AC trade, 21.6%, was recorded in July. While this was in coincidence with the departure of two AC technicians and the beginning of the summer-time where the demand for air-conditioning started to increase, this level was just slightly above the minimum utilization level of the PD technicians. The gap between it and the peak value of the EL trade was even greater than 30%.

4.3 Maintenance Performance

Having examined the maintenance demand and the effectiveness of the workforce, it is necessary to further investigate the outcome of maintenance work in order to ascertain its performance. To this end, downtime of the facilities is a useful indicator.

Based on the recorded downtimes for the various trades of work, a cumulative frequency diagram was constructed, as shown in Figure 10. All the cumulative frequency curves, except that for the AC trade, are highly similar. The downtime and hence the repair time for AC works were comparatively longer in most of the cases. From a Pareto-efficient perspective, 80% of the maintenance requests belonging to the EL, PD and BW trades were resolved in not more than 35 minutes whereas the AC trade required a longer period (40 minutes) to clear the same proportion of requests.

The curves in Figure 10 are not only useful for comparing the performances between different trades of work. They are a set of benchmarking curves that can be used for gauging the performances of the maintenance works in future. For example, the downtime of the AC trade at the 75th percentile, as found from this study, was below 35 minutes. A higher service level, e.g. a tighter repair time limit of 30 minutes, may be set as a new target. Achieving this target would mean that less than 25% of the AC maintenance problems would be fixed beyond the prescribed time limit (Table 2). Likewise, higher targets may be set for the EL, PD and BW trades in order to help improve their performance levels.

The analyses presented hitherto are up to the 'trade' level. It is possible to probe deeper into the maintenance performance by examining the downtimes of malfunctioned 'equipments' of the various trades. To start with, the following analysis was focussed on the most troublesome equipment.

Sorting the work orders in descending order of their occurrence frequencies found that blockage of water closet (WC), with a total count of 1,021, was the top maintenance problem, and it was encountered in 374 of the 618 guestroom toilets. Further checking, which was made by summing the downtimes of different types of malfunctioned equipments, confirmed that the aggregate downtime of WC blockage, being 11.63 days (i.e. 16,747 minutes), was the largest. Figure 11 shows that the major group of this problem were resolved in less than 10 minutes. Given a preset time limit of 45 minutes (Table 2), the technicians managed to fix over 90% of the problems without alerting their foreman.

Under the ARM approach, the concept of availability combines reliability and maintainability. The steady state or long term average availability of an item is represented by Equation (4) where *MTBF* is mean time between failures, *MTTR* is mean time to repair and *MTPM* is mean time for preventive maintenance[20].

$$A = \frac{MTBF}{MTBF + MTTR + MTPM} \quad (4)$$

The above representation, however, does not make distinctions between the availabilities for different types of systems or equipments under different circumstances. Among the various kinds of availabilities identified[21], e.g. intrinsic availability, operational availability, etc., standby availability is applicable for measuring the performance of WCs because they are down only when their failures are revealed while being called upon by the guests to function. In such cases, the standby availability (A_{sby}) of the system can be calculated by Equation (5) where TT and DT denote total time and downtime, respectively.

$$A_{sby} = \frac{TT - DT}{TT} \tag{5}$$

Referring to Equation (5), the standby availability for the i^{th} equipment of the system can be expressed as:

$$A_{sby(i)} = 1 - \frac{DT_i}{TT_i} \tag{6}$$

Hence, the standby availability of the same type of equipments in the system can be calculated by considering their total downtimes over the observed period. This is represented by Equation (7) where N is the total number of type I equipments.

$$A_{sby(I)} = 1 - \frac{\sum_{i=1}^{N} DT_i}{\sum_{i=1}^{N} TT_i} \tag{7}$$

The availabilities of the WCs during each of the 12 months were calculated using Equation (7). With an average value of 99.994%, the minimum and maximum availabilities were 99.989% and 99.998% respectively, indicating that this kind of equipments was actually reliable or readily maintainable regardless of the fact that it was the top repair item. It was expected that with a larger amount of maintenance manpower, the problems of WC blockage could be resolved faster, thus leading to a higher availability. This, however, is not supported by Figure 12, from which no apparent correlation could be found between available man-hours of the PD technicians and availability of the WCs. This may be because all the availabilities under investigation were high and the range of values they covered was narrow.

The remaining malfunctioned equipments in the hotel, which were less troublesome than the WCs, had even higher availabilities and so did not warrant further investigations using the same approach. Instead, efforts should be made in future to study the availabilities of facilities which frequently fail or require a long time for resolving their failures.

5. Conclusions

The studied hotel, which is a quality hotel, used a CMMS to keep track of its large volume of corrective maintenance works so as to promptly meet with its demanding end-user needs. The downtime of the malfunctioned facilities increased with the quantity of work orders issued for their rectification. The occupancy rates, which were generally high throughout the studied period, had insignificant influence on the variation in maintenance demand. Further work is needed to study whether, and how the maintenance demand would be affected by occupancy rates in the moderate and low ranges.

Rather than productivity (work output per worker), efficiency of the workers, which was computed in this study as the ratio between volume of work completed and actual amount of man-hours deployed, is a more exact measure for work effectiveness. Utilization level of the workforce is also an important parameter that should be investigated in order to augment the evaluation of work effectiveness.

With higher utilization levels of the workers, the efficiency of corrective maintenance works declined. It is worth-investigating if the same would apply on preventive maintenance works and whether the level of manpower utilized for preventive maintenance works would affect the work efficiency on corrective maintenance works.

Neither work efficiency nor manpower utilization was significantly affected by seasonal variation. Despite the comparatively higher utilization level of the electrical workers, their work efficiency was highly steady whereas the air-conditioning works, which are more variable in their complexities, were associated with irregular work efficiencies. Scrutinizing the utilization and efficiency levels of different trades of workers, which enabled reviewing their workloads and performances, is helpful to proper management of the maintenance team. Establishing benchmarking curves based on facilities' downtime are also useful for comparing the maintenance performances across different work trades. By setting appropriate performance targets, they can help achieve continuous improvement of the maintenance works.

Empirical studies using the ARM approach had been rare in the building services industry, but the foregoing analysis has demonstrated how the availability of facilities in buildings can be determined from real maintenance data. While this parameter can be an indicator for maintenance performance, it has limited use in examining work effectiveness when the facilities under investigation are reliable or can be readily maintained. More research effort is necessary for investigating the availabilities of facilities with low reliability or those which are hard to maintain.

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Table 1 Typical provisions in guestrooms

Area	Provisions
Living area	Bed, curtain, sofa, wardrobe, television, sound system, air-conditioning unit, lighting, sprinkler
Workspace & desk	Chair, desk with lamp, electrical socket, phone with voice mail, phone jack adapter, internet access, wireless data connection
Bathroom	Bathtub, floor drain, hairdryer, mirrors, scale, shaver socket, shower, water closet, wash basin, ventilating exhaust
Miscellaneous	In-room safe, card-key door lock, card-key switch, door bell, iron, ironing board, hanging closet, coffee/tea maker, mini-bar, mini-refrigerator

Table 2 Time limits for fixing maintenance problems

Trade	Time limits (minutes)	No. of job items	Example of problem
AC	30	18	Room air too cold
	45	1	Water dripping from air-conditioning unit
	60	5	Air-conditioning unit too noisy
EL	30	31	Lamp next to entrance door burnt
	45	37	No electrical supply to socket
	60	39	Lamp inside wardrobe burnt
	90	5	Fail to dim bedhead lamp
PD	30	6	Water leakage from WC cistern
	45	21	Blockage of WC
	180	3	Cracked wash basin
BW	20	10	Loosened entrance door handle
	30	37	Fail to open/close desk drawer
	40	2	Fail to open/close TV cabinet
	60	8	Loosened ceiling panel

Table 3 Time durations of a maintenance work order

Symbol	Representation
T_1	Time from failure to discovery of failure
T_2	Time for reporting failure to Front Office or Housekeeping Section
T_3	Time for relaying failure to GSC and recording it in CMMS
T_4	Time for categorising work request and issuing SMS work order
T_5	Maintenance time (within time limit)
T_6	Maintenance time (beyond time limit)
T_7	Time for reporting work order completion

Table 4 Statistics of job items and work orders

Trade	Job items (original)		Job items (corrected)		Work orders	
	No.	%	No.	%	No.	%
AC	84	11.04	82	10.96	1223	6.87
EL	312	41.00	316	42.25	8898	49.99
PD	189	24.84	148	19.79	4426	24.87
BW	176	23.13	201	26.87	2921	16.41
UC	0	0.00	1	0.13	331	1.86
Total	761	100.00	748	100.00	17799	100.00

Table 5 Monthly manpower available

Trade	Headcounts (No.)			Man-hours (Hours)		
	Mean	Min.	Max.	Mean	Min.	Max.
AC	2.92	2.00	4.00	521.3	384.0	672.0
EL	3.83	3.00	4.00	683.0	432.0	768.0
PD	3.25	3.00	4.00	592.9	545.0	809.0
BW	5.00	5.00	5.00	952.7	840.0	1,024.0

Table 6 Statistics of monthly work orders

Trade	No.				Downtime (minutes)			
	Mean	Min.	Max.	C_v	Mean	Min.	Max.	C_v
AC	107.4	73	162	26.3	2814.6	1525.5	4967.5	36.7
EL	774.9	654	911	11.3	15200.2	13439.0	17419.5	8.3
PD	388.6	297	515	16.7	8482.3	6521.5	12602.5	20.7
BW	256.1	202	317	14.7	5990.6	4071.1	9179.2	29.6

Note: C_v equals the ratio between standard deviation and mean, multiplied by 100.

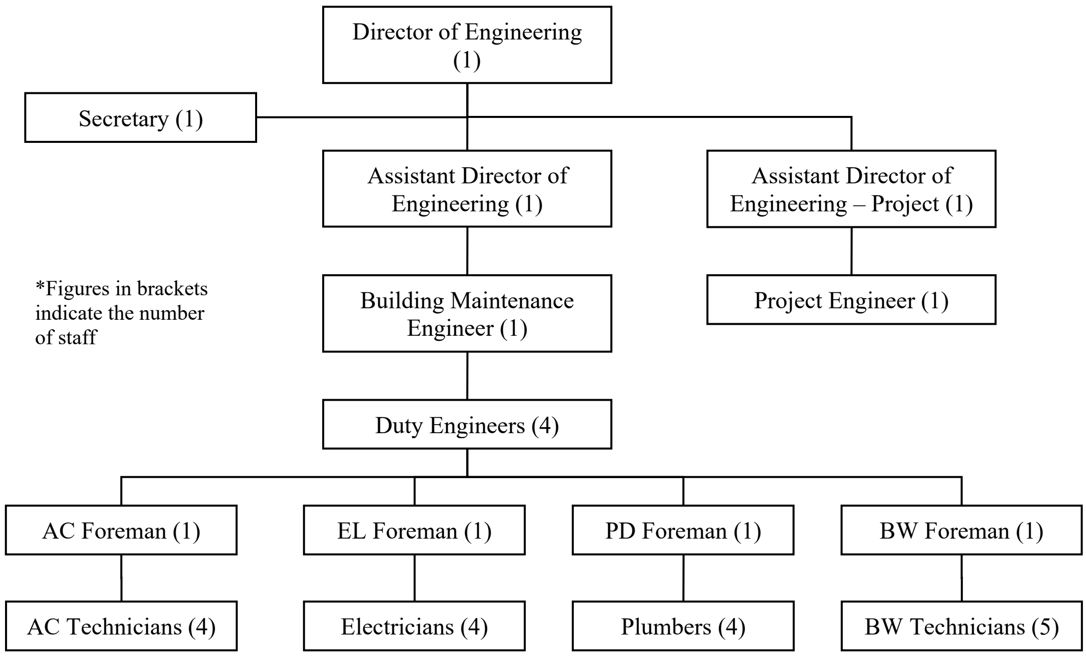

Figure 1 Organization of the engineering department

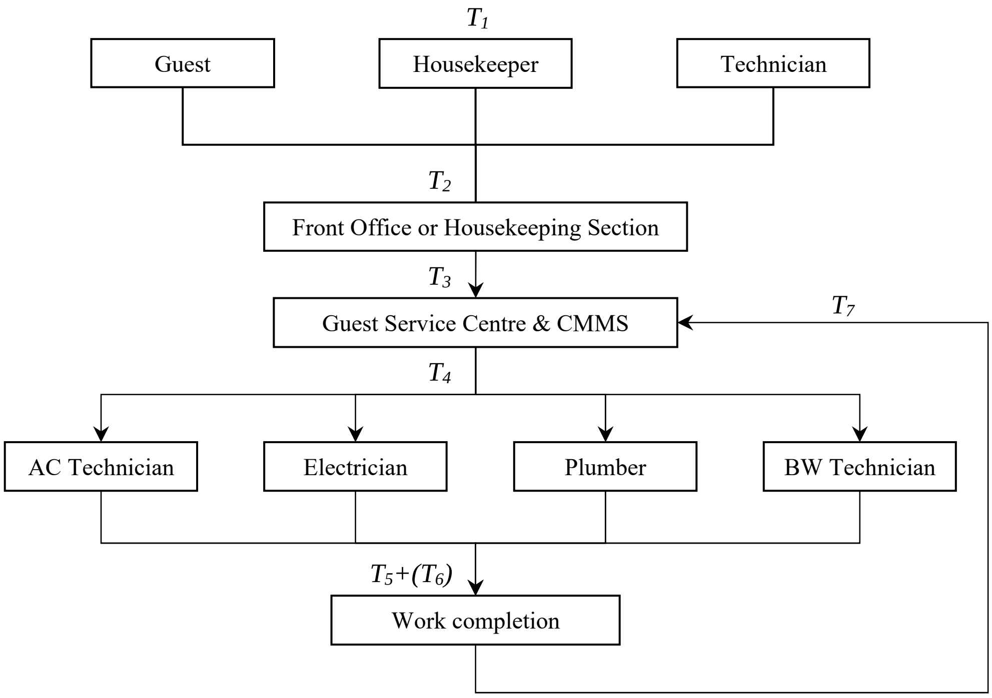

Figure 2 Flow of maintenance work execution

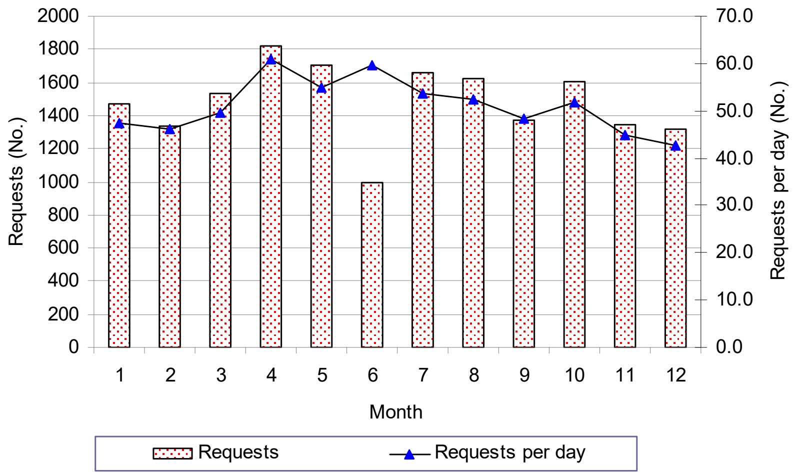

Figure 3 Volumes of maintenance requests

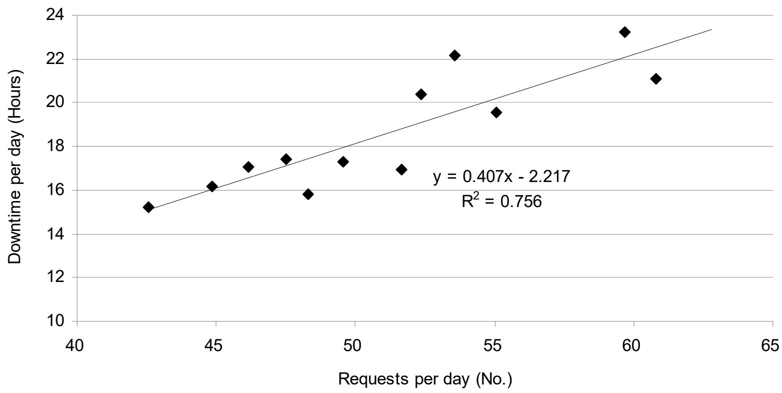

Figure 4 Correlation between downtime and number of requests

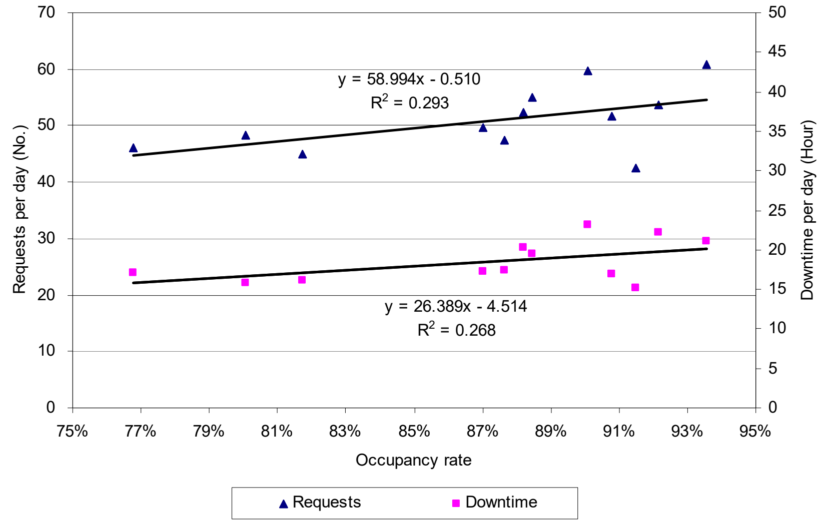

Figure 5 Occupancy rate and maintenance demand

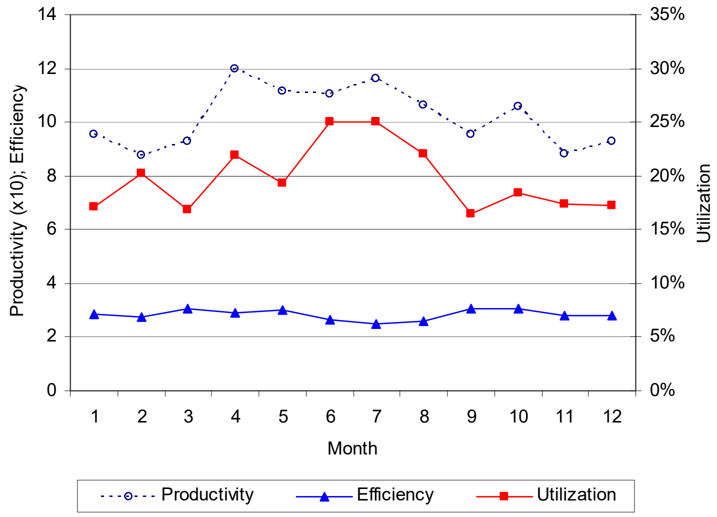

Figure 6 Efficiency, productivity and utilization of manpower

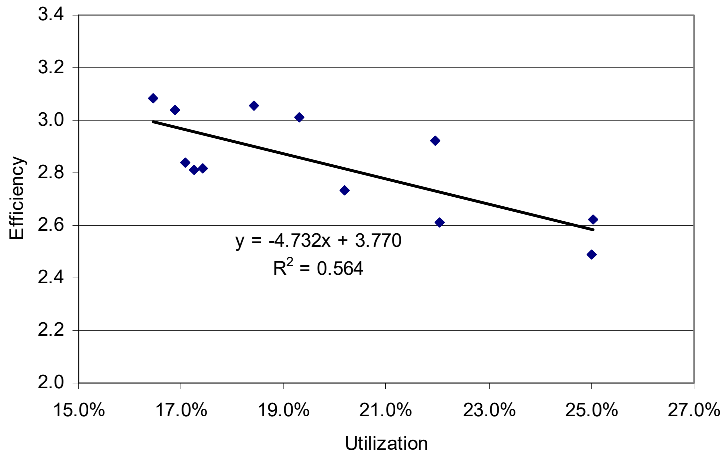

Figure 7 Relation between work efficiency and manpower utilization

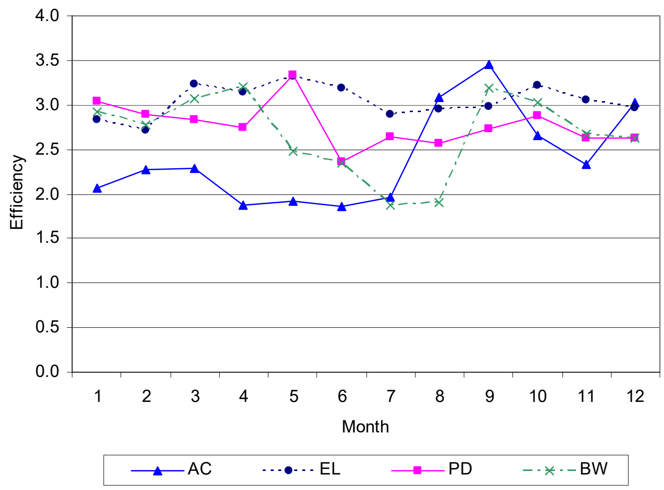

Figure 8 Efficiency levels of different trades of work

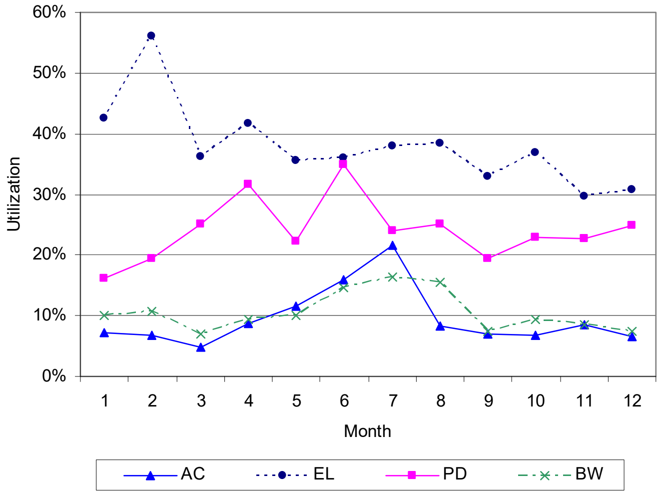

Figure 9 Utilization levels of different trades of work

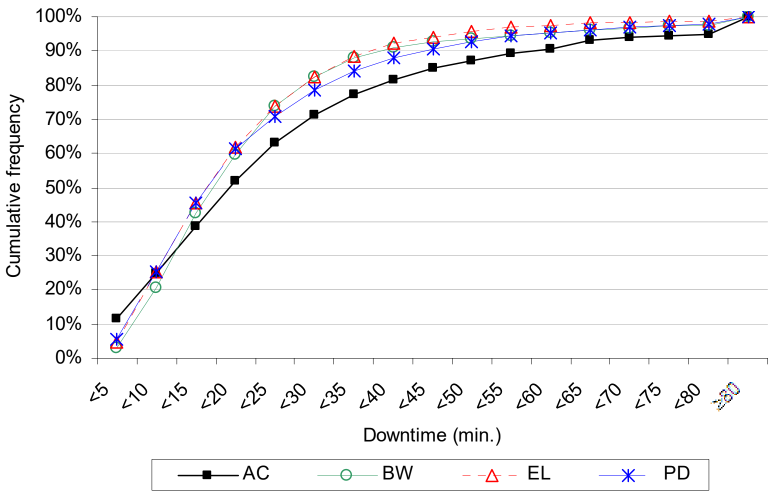

Figure 10 Cumulative frequency of downtimes of different trades

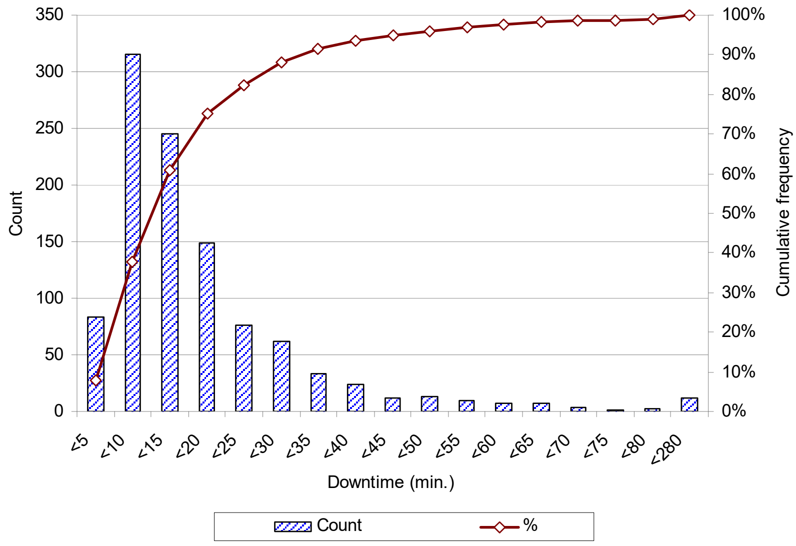

Figure 11 Downtime distribution of WC blockage

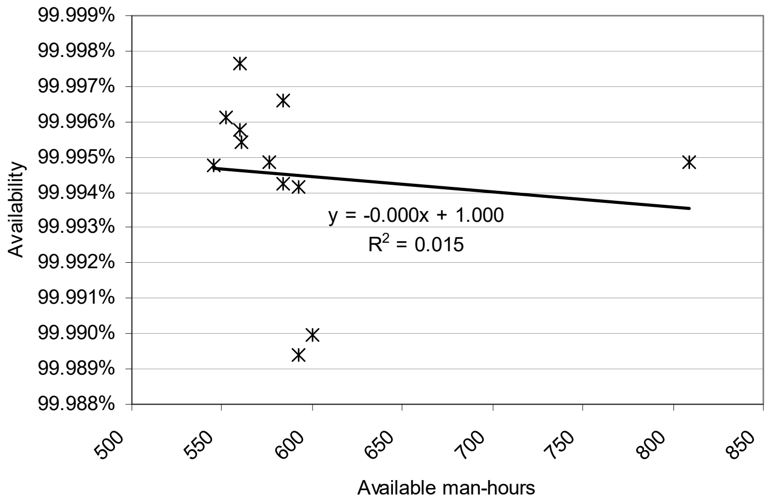

Figure 12 Availability of water closets