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AN ANALYSIS OF MAINTENANCE DEMAND, MANPOWER, AND PERFORMANCE OF HOTEL ENGINEERING FACILITIES

Abstract:

Research on maintenance for hotel engineering facilities is rare. Aimed at providing empirical findings for this niche area, an exploratory study was conducted based on the computerized maintenance management data of a hotel and the relevant records of its maintenance works. Segregated according to the period, place and physical installation ("3P") of the works, the data were analyzed by a series of statistical, regression and correlation analyses. The maintenance demand of the daytime electrical work in the guestrooms was found to dominate over those of the air-conditioning, plumbing and drainage, and builder's works. The performances of the four trades of works, while exhibiting strong correlations with their demands, were not correlated with their manpower inputs. A range of statistical benchmarks and regression models were developed, which can help hoteliers evaluate their maintenance works and serve as reference for future research in this area.

Keywords:

Empirical analysis; engineering facilities; maintenance demand; manpower input; work performance.

INTRODUCTION

Hotels are increasingly equipped with state-of-the-art facilities to meet the rising expectation of their patrons. Especially for engineering facilities such as electrical and air-conditioning installations, they need to be maintained incessantly in order to perform satisfactorily, underpinning the round-the-clock hotel operations. Without proper maintenance, for instance, the electrical system in a hotel would fail, leading to power outage. Besides causing disruptions, which is a service quality issue, delayed rectification of the problem is a safety matter that would violate the relevant statutory requirement (Lai & Yik, 2004). The consequential loss and legal implication can be substantial.

Prompt actions, therefore, are crucial for resolving any malfunctioned facilities. For this purpose, the engineering department of a hotel typically engages a group of resident staff to provide timely maintenance works for its facilities (DeFranco & Sheridan, 2007). To enable online tracking of maintenance works, more and more hotels have made use of computerized maintenance management systems (CMMS) to record the information of their maintenance work orders, such as when the orders were issued, where the works were done, and when the orders were completed.

The importance of maintenance for engineering facilities in hotels has been well recognized for a long time (Borsenik, 1977). Maintenance is also known as a key guest-satisfaction component of hotels (Mattila & O'Neill, 2003). But rather than maintenance, energy consumption has been a widely studied engineering issue of hotels (e.g. Deng & Burnett, 2002; Priyadarsini, Wu, & Lee, 2009) because of its prominent cost and environmental impacts.

In fact, buildings with higher energy performance are associated with maintenance personnel who are better remunerated (Yik, Lee, & Ng, 2002). A recent benchmarking study on a group of hotels has uncovered that the costs due to routine maintenance works and hiring of maintenance staff are comparable to the substantial amount of energy cost (Lai & Yik, 2008). As such, hotel managers have a vital role to play in ensuring the productivity of their maintenance teams and hence the effectiveness of maintenance works.

Productivity of hotels has long been a hot topic of discussion (Witt & Witt, 1989; Lee-Ross & Ingold, 1994; Baker & Riley, 1994). Empirical investigations on the productivity of hotels also have a long trail in research. For instance, Ball, Johnson, & Slattery (1986) conducted an analysis on the levels of labour productivity within the food and beverage departments of a hotel company in UK. Kilic & Okumus (2005), through collecting empirical data from a group of four and five-star hotels, investigated the factors influencing the productivity in hotels.

In the industrial sector where the deployment of labor is intensive, it is important to appropriately measure the performance of maintenance organizations (Tsang, 2009) and, along this line, a number of measurement approaches had been developed. The work of Dwight (1999), for example, recognized the practical problems in defining maintenance performance in terms of changes in value and developed a "systems audit approach" for measuring the performance of a maintenance system. After a review of the literature on performance measurement, Kutucuoglu, Hamali, Irani & Sharp (2001) introduced a framework for managing maintenance and applied it in a case study which focused on a manufacturing enterprise. The study of Parida & Kumar (2006), which was intended to identify the issues and challenges associated with implementation of a maintenance performance measurement system, presented a concept of total maintenance effectiveness for measuring maintenance performance.

Adoption of the above approaches in measuring the performance of hotel engineering is yet to be seen. Studies which particularly examine the productivity of hotels' maintenance labour are rare. While Chan, Lee, & Burnett (2001) had attempted to study the maintenance performance of a hotel, the literature identified so far was unable to tell whether or how the performance of hotel engineering facilities would vary with the levels of maintenance demand and maintenance manpower.

In order to bridge the above knowledge gap, an empirical study was conducted on a hotel. In the next section, the methodology of the study, including its research framework, the data collection process and the types of data collected, will be described. Then, a series of analyses on the maintenance demand of the hotel, its manpower input for producing maintenance works, and the maintenance performance of its facilities will be reported. After unveiling the relationships between these elements, the implications of the findings will be discussed, followed by some suggestions for further studies.

METHODOLOGY

The study, being a pilot of its kind, is exploratory in nature. The required maintenance data, which are often regarded as sensitive, are typically restricted from disclosure by the information barriers of their owners (Lai & Yik, 2006). To start with, therefore, the study team approached a hotel which is willing to provide its maintenance data for study in order to strive for quality improvement, and solicited from its senior management the consent of participating in the study.

The hotel was a typical four-star hotel situated in the downtown area of Hong Kong. With a gross floor area of over 40,000 m^2, the hotel building was 19-storey high and 33 years old, accommodating 618 guestrooms and other non-guestroom areas, such as function rooms, food and beverage outlets, kitchens, foyer and lobbies. The size of the hotel and its energy performance (1,748 MJ/m^2/year) were close to the mean levels of the luxury hotels investigated in the earlier benchmarking study (Lai & Yik, 2008).

In the hotel, the air-conditioned areas were mainly served by fan-coil units and the major type of interior lighting was incandescent lamp. Renovation works were carried out in phases, with typically three guestroom floors grouped for renovation over a period of three months, and the period for renovating up to two function rooms or food and beverage outlets was usually between two to four months. Each of such renovation cycles was between 10 and 15 years. All preventive and corrective maintenance works in the hotel, except the statutory maintenance works that must be undertaken by registered contractors (e.g. regular inspection, testing and examination of the lifts by a registered lift contractor), were carried out by an in-house maintenance team.

Since no previous studies of this kind could be found from the open literature, exactly what sorts of data should be collected and how they should be analysed to achieve the aim of the study was uncertain. For overcoming these difficulties, the applicable performance measurement principles (De Groote, 1995; Neely, Gregory & Platts, 1995), the design for measuring and reporting maintenance performance (Neely, Richards, Mills, Platts & Bourne, 1997; Pintelon & Van Puyvelde, 1997), the relevant maintenance standard (BSI, 2007), and the previous experience of collecting empirical maintenance data (Lai & Yik, 2008; Lai, Yik & Jones, 2008) were taken into account to formulate a research framework to guide the data collection and analysis processes of this study.

Research Framework

As shown in Figure 1, the framework consists of three tiers - period, place and physical installation (i.e. "3P" framework). Identification of the first tier of this framework was based on the premise that the maintenance demand and hence the manpower input and the performance of maintenance work would be different in different time periods. In this study, the two distinct operational periods of the hotel are daytime (0800 – 2259) and nighttime (2300 – 0759). In the latter period, which is the normal sleeping period of the guests, the functions and activities in the hotel would be much less than those in the daytime.

"Take in Figure 1"

In the second tier, the data in each of the daytime and nighttime groups are subdivided according to where the maintenance work takes place, anticipating that the work would be affected by the user needs which differ between the guestroom areas and the non-guestroom areas. Under each of these subgroups, the data are further divided with respect to the physical characteristics of the maintenance work, as shown in the final tier. Classified according to the specialist skills of the maintenance workers, the four trades of work are air-conditioning (AC), electrical (EL), plumbing and drainage (PD) and builder's work (BW), which are different in nature and complexity. Common examples of the problems corresponding to these four trades are: room air is too warm; a lamp is burnt; a water closet is choked; and a door lock is broken.

Data Collection

Before collecting the data, a meeting was held with the hotel's maintenance team. At this meeting, the purpose of the study and the types and extents of data needed were explained to the director of engineering and his subordinates. Meanwhile, the maintenance team briefed the study team about how the maintenance works were organized and executed. The study team was then guided to walk through the main areas, including the places where the major facilities were located and the typical rooms of the hotel. The corrective maintenance works for the facilities, which necessitate swift actions to be taken in order to satisfy the demanding end-users, were recorded by a CMMS. At the Service Centre where the CMMS was located, the process of issuing and recording the maintenance work orders was observed.

After the meeting and the subsequent communications with the maintenance staff, the requested data were provided to the study team in batches, among them a set of electronic files storing the maintenance work orders over a period of 12 months was retrieved from the CMMS. The information recorded in these files include the date of each work order, its start time and end time, where the work was executed, and what complaints or maintenance problems were raised (e.g. a fan-coil unit was too noisy, a light switch failed, etc.).

In addition, a set of monthly duty rosters was collected. On each of these rosters, the periods on each day during which each maintenance worker was on duty or on leave were indicated. But because these were manual records, the study team had to enter the entries of each day into an electronic spreadsheet before the data could be analysed.

ANALYSIS AND DISCUSSION

From the CMMS record, the raw total number of work orders issued over the 12-month period was 17,799. But when the number of work orders in each month was counted to investigate the monthly variations in maintenance demand, it was discovered that the work order records in two periods (18-30 June and 29-30 September) were lost because of the breakdowns of the CMMS. To enable comparisons to be made across the twelve months, the number of work orders in the above two months was divided by the actual number of days with data in the respective month to yield an average number per day, and the work orders issued on the days with missing data were assumed to be equal to the average number so calculated. After these adjustments, the total amount of work orders became 18,668 (i.e. 4.7% of all data were treated with the assumption).

In the following analyses, the volume of work orders was used as a measure for maintenance demand. The amount of man-hours of the relevant technicians and the amount of facilities downtimes were used for measuring the levels of maintenance manpower and maintenance performance, respectively.

Maintenance Demand

Of all the work orders, the majority (95.3%) were demanded during the daytime and the remaining 4.7% at night. When grouped according to where the works took place, the guestrooms accounted for 81.8% whereas the orders in the non-guestroom areas were 18.2%.

Classifying the orders by work trades showed that the electrical work was dominant (49.8%), followed by plumbing and drainage (25.0%), builder's work (16.5%) and air-conditioning (6.9%). The remaining 1.8% of the orders could not be classified as their descriptions were unclear even after making clarification with the maintenance staff. Following the research framework in Figure 1, the statistics obtained based on the monthly numbers of work orders, which include the values of minimum, maximum, mean, standard deviation (*SD*) and coefficient of variation (C_v), are summarised in Table 1a.

"Take in Table 1a, 1b, 1c"

On average, the maintenance team handled 1,555.7 work orders per month, or 51.9 orders per day. Inspecting across the mean values of the four trades revealed that the majority of the maintenance demand arose from the guestrooms during the daytime. The amounts of work orders recorded for the non-guestroom areas at night were small. Unlike the significant difference between the minimum numbers of work orders issued for the guestrooms and the non-guestroom areas during the daytime pertaining to the EL, PD and BW trades, the magnitudes of the AC counterparts were comparable. Similar observations are noted from the maximum values.

Regarding the distribution of the monthly amounts of work order, the largest spread (*SD* = 86.4) was found with the daytime electrical work in the guestrooms. But the comparatively small coefficient of variation (C_v = 13.9) of this subgroup tells that the fluctuation of its workload was not high. The workload of the nighttime builder's work in the non-guestroom areas, though being small on average (2.6), was the most variable (C_v = 108.6). The large C_v values associated with the night work in the non-guestroom areas of the other three trades, which ranged between 91.2 and 98.6, indicate that their workloads were also highly variable.

As the preceding analysis shows, the major maintenance demand came from the guestrooms during the daytime. In order to compare such monthly demands on an equal basis, the number of orders issued in each month was divided by the number of days in the corresponding month to yield its normalized monthly mean number of orders per day. The results for the four trades of work calculated by this method are shown in Figure 2.

"Take in Figure 2"

Throughout the period studied, there were no crossovers or overlaps between the monthly mean daily demands of the four trades of work. Clearly, the dominant trade was electrical, with its highest and lowest demands being in April and January, respectively. The curve of the plumbing and drainage work resembles a similar pattern but the trough of its demand occurred in September instead of January. As to the builder's work and air-conditioning work, their demands were relatively low and steady.

Maintenance Manpower

The recorded maintenance works were carried out by a total of 17 technicians. They include four AC mechanics, four electricians, four plumbers and five builder's work tradesmen, who were arranged to work on four shifts a day (Figure 3). Since the technicians were sometimes on vacations or sick leaves and there were occasional changes in their duty schedules in order to cope with the operational needs, the amounts of on-duty manpower actually varied from time to time.

"Take in Figure 3"

In order to figure out the real amounts of manpower available for performing the maintenance work, the duration of each technician who was on duty in each shift was computed. The man-hours input for each work trade were calculated by summing the relevant man-hours of all technicians in the same trade. This was done for each day and then for each month. The daily man-hours for each trade were further separated into two groups, one for the daytime and the other for the nighttime. In total, the annual amount of man-hours was 33,083, with 87.7% being in the daytime and 12.3% at night. A summary of the statistics worked out based on the monthly man-hours is shown in Table 1b.

As evidenced by the small coefficient of variation (5.5), the total available manpower was rather stable across the months. The mean monthly value of 2,756.9 is equivalent to having 11.5 technicians working for eight hours a day. Unlike the summary in Table 1a where subgroups of work orders are shown for the guestroom and non-guestroom areas, the amounts of man-hours could not be subdivided in the same way because, in reality, the technicians had to carry out the maintenance works irrespective of their locations. Nevertheless, the available manpower, as shown in Table 1b, was grouped into two periods (i.e. daytime and nighttime) for analysis.

It is obvious that the majority of the manpower were available during the daytime. Given that the numbers of mechanics, electricians and plumbers were identical, the minimum, maximum, mean, *SD* and C_v values pertaining to the daytime period are comparable across the three trades. Whereas the available manpower for builder's work was the highest, its variations during the daytime were small (C_v = 5.6).

At night, much of the available manpower was contributed by the electricians and plumbers. On average, the air-conditioning manpower level was low (31.3), and that of the builder's work was even lower (13.0). In the extreme situation, no builder's work tradesmen were on duty. Furthermore, the largest C_v value of the builder's work indicates that the manpower availability of this trade was highly variable.

Similar to the normalization made for the maintenance demand, the available manpower during the daytime in each month was normalized by dividing its value by the number of days in the respective month. The values calculated in this way for each of the four trades are plotted in Figure 4. It shows that the level of manpower of the BW trade was the highest and was relatively steady throughout the year. Despite the apparently comparable levels of the other three trades, the level of air-conditioning manpower actually varied. The two troughs of this trade, due to the departure of two mechanics, occurred in July and December.

"Take in Figure 4"

In January and February, an obvious drop in manpower was found with the electrical trade because only three of the four electrician posts were filled in that period. While the manpower level of plumbers seemed to be stable most the time, a full team of plumbers only appeared in January. Throughout the year, the minimum level was 11.6 man-hours per day, which was associated with the air-conditioning trade.

Maintenance Performance

The difference between the start time and the end time of each work order was calculated as the downtime of the corresponding facility. The downtimes aggregated from the four trades of work over the period studied was 6,782.7 hours, i.e. 18.6 hours a day on average. With only 4.6% of such downtimes being within the sleeping period, most (95.4%) occurred during the daytime. 75.9% of the downtimes were due to facilities malfunctions in the guestrooms and those arising from the non-guestroom areas constituted around one-fourth of the total amount. The shares of downtimes contributed by the four trades, in descending order, were 44.8% (electrical), 25.0% (plumbing and drainage), 17.9% (builder's work) and 8.3% (air-conditioning), with the remaining 4.2% attributed to some items which could not be classified based on their descriptions in the record.

In fact, there were some time limits for fixing the commonly found maintenance problems in the hotel. Ranging from 30 to 180 minutes, the time limits varied with the urgency of the problems and the difficulty in solving them. For instance, a complaint from a guest about "room air too cold" needs to be settled in 30 minutes; the time limit for rectifying a malfunctioned bedhead lamp was 90 minutes; and the counterpart for repairing a cracked wash basin was 180 minutes. While such time limits had been set for individual maintenance jobs, the statistics displayed in Table 1c, which were obtained from the present study by grouping the monthly facilities downtimes (in hours) according to the "3P" research framework, can serve as benchmarks for gauging the speediness of different trades of work.

With a mean monthly value of 565.2 hours, the variations of the total downtimes across the twelve months were mild (*SD* = 81.8; C_V = 14.5). In contrast, the large C_V values, which ranged between 101.6 and 165.4, imply that there were severe fluctuations in the downtimes during the nighttime. Furthermore, inspecting the mean downtime values across the various trades found that the amounts of downtime at night, as compared to those in the daytime (range: 12.8 - 201.3), were minimal (range: 1.1 - 7.1).

Same as the normalization applied to the maintenance demand before, the amounts of downtime pertaining to the guestrooms during the daytime were normalized by the number of days in the respective months. The calculated results, grouped by the four trades, are shown in Figure 5. The monthly downtimes due to the malfunctioning of the electrical installations were the largest. Identical to the observations from the maintenance demand (Figure 2), the downtime of the EL trade peaked in April and its trough was in January.

"Take in Figure 5"

The plumbing and drainage installations, in terms of downtime, were the second most troublesome trade of work. The largest downtime of this trade, which happened in June, was close to that of the EL trade in the same month. The levels of its troughs, in February and September, were comparable to the highest level of the builder's work in June. Besides, the peak downtime level of the air-conditioning installations occurred in July (summer) whereas the lowest level was in December (winter).

Relationships between Maintenance Demand, Manpower, and Performance

The foregoing findings have proved that the maintenance demand, the manpower deployed, and the downtime of the malfunctioned facilities were associated mainly with the daytime period. Figure 6, portraying the facilities' downtime distributions, further shows the small aggregate downtime of the four trades during the nighttime. The largest group of orders of such downtime distribution, which was resolved between five and nine minutes, amounted to 170 only. The pattern of this distribution is comparable to the distribution curve of the daytime air-conditioning work, which was the least troublesome trade in terms of downtime. For the other three trades, i.e. EL, PD and BW, the shapes of their downtime distribution curves are similar, and their majority groups of orders were completed between five and 14 minutes.

"Take in Figure 6"

In principle, the output level of a maintenance process is dependent on the level of demand for the relevant maintenance work and the level of resources input for producing the work. While a bigger maintenance demand should give rise to a lower output in maintenance performance, a larger input of maintenance manpower should lead to a higher level of output performance. In the ensuing analysis, the output level (i.e. dependent variable y) was measured by the monthly hours of downtime. Two independent variables, namely the demand and the input levels, were measured by the monthly number of work orders (x_1) and the monthly amount of man-hours (x_2) respectively. For analysing how the output level was related to the demand and input levels of the maintenance process, the following multiple regression model was used, where β_0, β_1 and β_2 are the parameters and ε is a random variable:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon \qquad (1)$$

Based on Equation (1) and the maintenance demands, inputs and outputs of the facilities during the daytime period, regression analysis was performed for each of the four trades of work. The results of the regression statistics, including the values of multiple coefficient of determination (R^2), adjusted R^2, F test, and the coefficients and p-values of the variables in the regression model, are summarized in Table 2.

“Take in Table 2”

The large value of R^2 found with the EL trade indicates that 90.84% of the variability in the output (downtime) of electrical maintenance work is explained by the estimated multiple regression equation with the maintenance demand and maintenance manpower as the independent variables. The R^2 values of the other three trades, ranging from 0.5854 to 0.7903, tell that the goodness of fit of their respective estimated regression equations are between moderate and high. Similar observations are noted from the adjusted R^2 values, which varied between 0.4933 and 0.8880.

With a level of significance $\alpha = 0.01$, the significance F values show that a significant relationship existed in the multiple regression equations for the first three trades. Thus, the relationships between the maintenance demand, manpower and performance of the air-conditioning, electrical, and plumbing and drainage works can be shown as Equation (2), (3) and (4), respectively:

$$y_{AC} = -11.3682 + 0.5599x_{1_{AC}} + 0.0015x_{2_{AC}} \tag{2}$$

$$y_{EL} = 128.0499 + 0.2649x_{1_{EL}} - 0.1572x_{2_{EL}} \tag{3}$$

$$y_{PD} = -31.0926 + 0.4190x_{1_{PD}} + 0.0231x_{2_{PD}} \tag{4}$$

The significance F value of the regression equation for the builder’s work exceeded 0.01, meaning that no significant relationship was found between the parameters. Besides the small range of manpower input (see Table 1b), the possibility that the manpower productivity was invariable is a plausible reason for this observation.

From a scrutiny on the *p*-values of the intercept and the independent variables of the regression equations, statistical significance was found with the demand variable for the trades of AC, PD and BW. In the case of electrical work, the same was found not only with the demand variable but also with the intercept and the input variable, which confirms the particularly high goodness of fit of its regression equation.

It is a logical presumption that maintenance demand and manpower input are two independent variables. But if they were highly correlated with each other, multicollinearity might exist in the multiple regression equations. In order to test the degree of linear association between these two variables, the Pearson correlation coefficient (r) was calculated between each pair of variables in the regression models. This was done for each trade and the calculated results are shown in Table 3.

“Take in Table 3”

Across the four trades, the output variable was significantly correlated with the demand variable ($r = 0.765$ to 0.887). No significant correlation existed between the output variable and the input variable ($r = -0.309$ to 0.235). There was also no significant correlation between the demand variable and the input variable as all their significance values exceeded α. Furthermore, the correlation coefficients between these two variables ($r = -0.367$ to 0.506) are all in compliance with the rule of thumb test ($| r | < 0.7$) for multicollinearity. Therefore, it can be concluded that maintenance demand and manpower input are two independent variables and so multicollinearity did not exist in the multiple regression models.

To unveil more clearly the correlation between the output performance of the maintenance work and the demand and input variables, two scatter-plots were prepared. It can be seen from Figure 7a that for all the four trades of work, their performances were highly correlated with their maintenance demands although only a moderate goodness of fit ($R^2 = 0.5560$) was found with the simple linear regression line for the builder's work.

"Take in Figure 7a, 7b"

In Figure 7b, however, none of the four trades shows any apparent correlation. The negligible R^2 values (between 0.0000 and 0.0989) also indicate that all the simple linear regression lines could not fit well to depict the relationships between the variables in the four cases. While in principle a larger manpower should be more able to handle a larger amount of maintenance work, the above observations suggest that the performance of the maintenance works was independent of the levels of manpower deployed. Identification of the reasons or factors leading to these findings entails further investigations in future.

CONCLUSIONS

Maintenance for engineering facilities in hotels was an underexplored research area. A basic obstacle to pursuing studies in this area, as unveiled by this research study, is the lack of complete record data. While the result of this study is limited by the assumption made for the missing data, this informs the need for enhancing the data recording system of the studied hotel and highlights the importance of checking the completeness of CMMS data record when carrying out similar research work in future.

By segregating the hotel's maintenance data according to the "3P" (i.e. period, place and physical installation) research framework, the study has illustrated how the demand, input manpower and performance of the maintenance works can be analyzed in a systematic manner. The findings obtained from the statistical analyses, including the values of mean, minimum, maximum, standard deviation and coefficient of variation of the maintenance work orders, input man-hours and facilities downtimes, can be used in internal performance benchmarking for the hotel. This would enable the hotel's management to identify any room for improving the maintenance works and, at the same time, feedback to the maintenance team the performance level they have achieved. When similar findings are made available from other hotels, external benchmarking of the maintenance performance between peer hotels can be made.

With most of the demand for maintenance works being in the guestrooms during the daytime, the major workload was due to the electrical work. This not only justifies the deployment of more electrical workers but also implies the significant influence of the electrical work on the overall maintenance performance. Particular attention, therefore, should be paid to this trade of work in cases of manpower reorganization or outsourcing for the maintenance works.

As the multiple regression analyses showed, the air-conditioning, electrical and plumbing and drainage works in the daytime can be modeled by using their respective maintenance demand and manpower input as independent variables and their output performance as the dependent variable. The regression models developed, apart from being useful for prediction of the achievable downtimes of the three trades of works, can be used for determining the levels of manpower required for handling different levels of maintenance demand. Yet, further investigations are needed to explore whether or how the builder's work could be modeled.

The correlation analyses revealed that the performance of each trade of work was highly correlated with the level of its maintenance demand. On the other hand, there was no significant relationship between the performance and the input manpower of the maintenance work. While being informative to the management team of the hotel, this finding should warrant further studies to investigate its underlying causes and in what way the maintenance performance could be improved through optimization of the manpower resources.

REFERENCES

Baker, M. & Riley, M. (1994). New perspectives on productivity in hotels: some advances and new directions. *International Journal of Hospitality Management, 13*(4), 297-311.

Ball, S.D., Johnson, K. & Slattery, P. (1986). Labour productivity in hotels: an empirical analysis. *International Journal of Hospitality Management, 5*(3), 141-147.

Borsenik, F.D. (1977). The Role of the Engineering and Maintenance Course in Hospitality Education. *Journal of Hospitality & Tourism Research, 2*, 39-46.

BSI (2007). *Maintenance - Maintenance Key Performance Indicators (BS EN 15341:2007).* British Standard Institution.

Chan K.T., Lee, R.H.K. & Burnett, J. (2001). Maintenance performance: a case study of hospitality engineering systems. *Facilities, 19*(13/14), 494-503.

DeFranco, A.L. & Sheridan, S.B. (2007). The Engineering Department and Financial Information. In D.G. Rutherford, & M.J. O'Fallon (Eds.), *Hotel Management and Operations* (pp. 199-205). Hoboken, N.J.: John Wiley.

De Groote, P. (1995). Maintenance performance analysis: a practical approach. *Journal of Quality in Maintenance Engineering, 1*(2), 4-24.

Deng, S. & Burnett, J. (2002). Energy use and management in hotels in Hong Kong. *International Journal of Hospitality Management, 21*, 371-380.

Dwight, R. (1999). Searching for real maintenance performance measures. *Journal of Quality in Maintenance Engineering, 5*(3), 258-275.

Kilic, H. & Okumus, F. (2005). Factors influencing productivity in small island hotels: evidence from Northern Cyprus. *International Journal of Contemporary Hospitality Management, 17*(4), 315-331.

Kutucuoglu, K.Y., Hamali, J., Irani, Z. & Sharp, J.M. (2001). A framework for managing maintenance using performance measurement systems. *International Journal of Operations & Production Management, 21*(1/2), 173-194.

Lai, J.H.K. & Yik, F.W.H. (2004). Law and building services maintenance in Hong Kong. *Transactions of Hong Kong Institution of Engineers, 11*(1), 7-14.

Lai, J.H.K. & Yik, F.W.H. (2006). Developing Performance Indicators for Benchmarking Building Services Operation and Maintenance for Commercial Buildings. *Proceedings of CIBW70 Trondheim International Symposium: Changing User Demands on Buildings*, pp. 283-294.

Lai, J.H.K. & Yik, F.W.H. (2008). Benchmarking operation and maintenance costs of luxury hotels. *Journal of Facilities Management, 6*(4), 279-289.

Lai, J.H.K., Yik, F.W.H. & Jones, P. (2008). Expenditure on Operation and Maintenance Service and Rental Income of Commercial Buildings. *Facilities, 26* (5/6). 242-265.

Lee-Ross, D. & Ingold, T. (1994). Increasing productivity in small hotels: are academic proposals realistic? *International Journal of Hospitality Management, 13*(3), 201-207.

Mattila, A.S. & O’Neill, J.W. (2003). Relationships between Hotel Room Pricing, Occupancy, and Guest Satisfaction: A Longitudinal Case of a Midscale Hotel in the United States. *Journal of Hospitality & Tourism Research, 27*(3), 328-341.

Neely, A., Gregory, M. & Platts, K. (1995). Performance measurement system design: a literature review and research agenda. *International Journal of Operations & Production Management, 15*(4), 80-116.

Neely, A., Richards, H., Mills, J., Platts, K. & Bourne, M. (1997). Designing performance measures: a structured approach. *International Journal of Operations & Production Management, 17*(11), 1131-1152.

Parida, A. & Kumar, U. (2006). Maintenance performance measurement (MPM): issues and challenges. *Journal of Quality in Maintenance Engineering, 12*(3), 239-251.

Pintelon, L. & Van Puyvelde, F. (1997). Maintenance performance reporting systems: some experiences. *Journal of Quality in Maintenance Engineering, 3*(1), 1355-2511.

Priyadarsini, R., Wu, X. & Lee, S.E. (2009). A study on energy performance of hotel buildings in Singapore. *Energy and Buildings, 41*, 1319-1324.

Tsang, A. (2009). *Maintenance Performance Management in Capital Intensive Organizations: Key to Optimizing Management of Physical Infrastructure Assets*. Köln: Lambert Academic Publishing.

Witt, C.A. & Witt, S.F. (1989). Why productivity in the hotel sector is low. *International Journal of Contemporary Hospitality Management, 1*(2), 28-34.

Yik, F.W.H., Lee, W.L. & Ng, C.K. (2002). Building energy efficiency and the remunerations of operation and maintenance personnel. *Facilities, 20*(13/14), 406-413.

Table 1a Statistics of the monthly work orders

Physical (Trade)	Period	Place	Min	Max	Mean	*SD*	C_v
Air-conditioning	Day	G	30.0	108.0	62.1	23.4	37.7
		NG	21.0	46.0	33.8	8.4	24.9
	Night	G	4.0	15.0	5.9	3.2	53.7
		NG	0.0	17.0	5.6	5.5	98.6
Electrical	Day	G	497.0	765.0	622.7	86.4	13.9
		NG	97.0	164.8	123.5	21.2	17.1
	Night	G	10.0	38.0	21.3	8.4	39.6
		NG	0.0	21.0	7.5	7.2	96.2
Plumbing & drainage	Day	G	258.0	454.0	340.2	60.4	17.8
		NG	17.0	39.0	25.3	6.7	26.7
	Night	G	12.7	32.0	21.5	5.8	27.1
		NG	0.0	4.0	1.6	1.4	91.2
Builder's work	Day	G	154.0	236.4	194.5	26.5	13.6
		NG	32.0	71.0	53.9	12.3	22.7
	Night	G	2.0	10.0	5.0	2.5	49.4
		NG	0.0	10.0	2.6	2.9	108.6
Unclassified	Day	G	-	-	-	-	-
		NG	10.0	44.0	26.3	9.8	37.0
	Night	G	-	-	-	-	-
		NG	0.0	12.0	2.3	3.2	139.1
Total			1319.0	1824.0	1555.7	174.3	11.2

*G: guestroom areas; NG: non-guestroom areas.

Table 1b Statistics of the monthly man-hours

Period	Physical (Trade)	Min	Max	Mean	*SD*	C_v
Day	Air-conditioning	360.0	646.5	490.1	85.4	17.4
	Electrical	353.5	594.0	505.5	62.3	12.3
	Plumbing & drainage	384.5	641.5	480.8	73.0	15.2
	Builder's work	840.0	1008.0	940.2	53.0	5.6
Night	Air-conditioning	19.5	79.0	31.3	16.6	53.1
	Electrical	76.0	275.0	181.0	61.9	34.2
	Plumbing & drainage	28.5	206.5	115.1	51.5	44.7
	Builder's work	0.0	72.0	13.0	22.4	171.7
Total		2383.0	2953.0	2756.9	152.4	5.5

Table 1c Statistics of the monthly downtimes

Physical (Trade)	Period	Place	Min	Max	Mean	*SD*	C_v
Air-conditioning	Day	G	9.3	58.6	27.1	14.5	53.6
		NG	8.8	25.4	16.0	5.9	37.0
	Night	G	0.5	2.9	1.5	0.9	63.4
		NG	0.0	7.6	2.3	2.3	101.6
Electrical	Day	G	170.4	237.3	201.3	21.2	10.5
		NG	30.0	65.2	45.0	11.6	25.7
	Night	G	2.8	9.2	5.2	1.8	35.1
		NG	0.0	5.7	1.8	1.9	103.2
Plumbing & drainage	Day	G	86.8	188.4	120.4	28.9	24.0
		NG	5.7	22.6	12.8	5.2	40.4

	Night	G	3.9	8.7	7.1	1.9	26.5
		NG	0.0	4.6	1.1	1.4	132.7
Builder’s work	Day	G	49.6	90.4	64.6	11.5	17.8
		NG	10.5	68.8	31.1	19.0	61.2
	Night	G	0.3	3.7	1.7	1.0	58.0
		NG	0.0	10.2	2.4	3.1	127.3
Unclassified	Day	G	-	-	-	-	-
		NG	5.4	50.7	21.2	13.4	63.2
	Night	G	-	-	-	-	-
		NG	0.0	12.7	2.6	4.3	165.4
Total			472.7	696.0	565.2	81.8	14.5

*G: guestroom areas; NG: non-guestroom areas.

Table 2 Summary of regression statistics

Air-conditioning		Value	Significance
	R^2	0.7392	-
	Adjusted R^2	0.6813	-
	F	12.7568	0.0024**
		Coefficient	p-value
	Intercept	-11.3682	0.6686
	Demand	0.5599	0.0011**
	Input	0.0015	0.9693
Electrical		Value	Significance
	R^2	0.9084	-
	Adjusted R^2	0.8880	-
	F	44.6077	0.0000**
		Coefficient	p-value
	Intercept	128.0499	0.0001**
	Demand	0.2649	0.0000**
	Input	-0.1572	0.0024**
Plumbing & drainage		Value	Significance
	R^2	0.7903	-
	Adjusted R^2	0.7437	-
	F	16.9590	0.0009**
		Coefficient	p-value
	Intercept	-31.0926	0.4159
	Demand	0.4190	0.0003**
	Input	0.0231	0.7195
Builder’s work		Value	Significance
	R^2	0.5854	-
	Adjusted R^2	0.4933	-
	F	6.3549	0.0190
		Coefficient	p-value
	Intercept	-63.6130	0.5752
	Demand	0.5969	0.0065**
	Input	0.0117	0.9196

**Correlation is significant at the 0.01 level.

Table 3 Summary of Pearson correlation coefficients

		Demand	Input	Output
Air-conditioning	Demand	1	-0.367 (0.241)	0.860** (0.000)
	Input	-	1	-0.309 (0.328)
	Output	-	-	1
Electrical	Demand	1	0.506 (0.094)	0.856** (0.000)
	Input	-	1	0.071 (0.828)
	Output	-	-	1
Plumbing & drainage	Demand	1	0.202 (0.529)	0.887** (0.000)
	Input	-	1	0.235 (0.463)
	Output	-	-	1
Builder’s work	Demand	1	0.127 (0.693)	0.765** (0.004)
	Input	-	1	0.120 (0.711)
	Output	-	-	1

**Correlation is significant at the 0.01 level; 2-tailed significance values are in the parentheses.

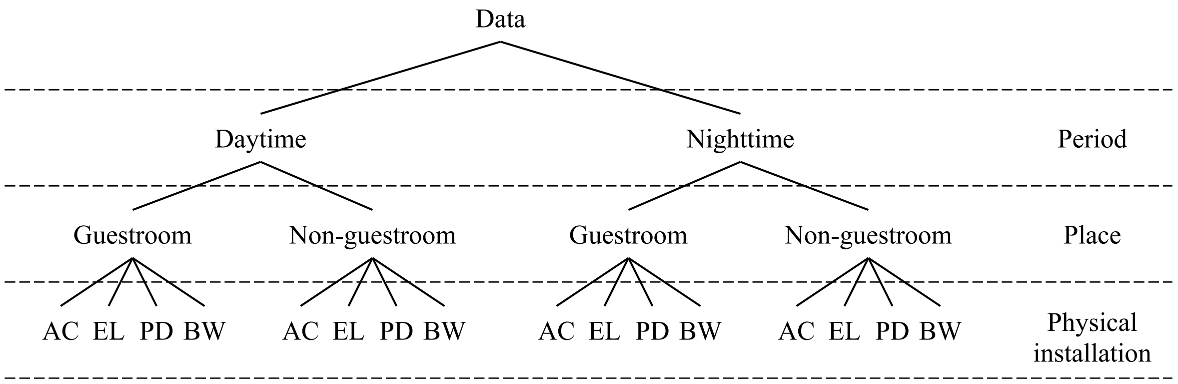

Figure 1 The “3P” research framework

Lai, J.H.K. (2013), An analysis of the maintenance demand, manpower and performance of hotel engineering facilities, Journal of Hospitality & Tourism Research, Vol. 37, No. 3, pp. 426-444

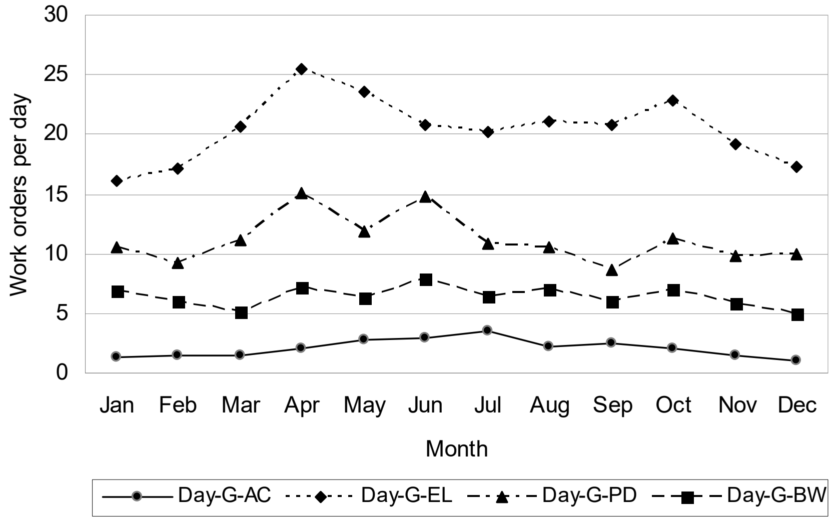

Figure 2 Variation of maintenance demand

Lai, J.H.K. (2013), An analysis of the maintenance demand, manpower and performance of hotel engineering facilities, Journal of Hospitality & Tourism Research, Vol. 37, No. 3, pp. 426-444

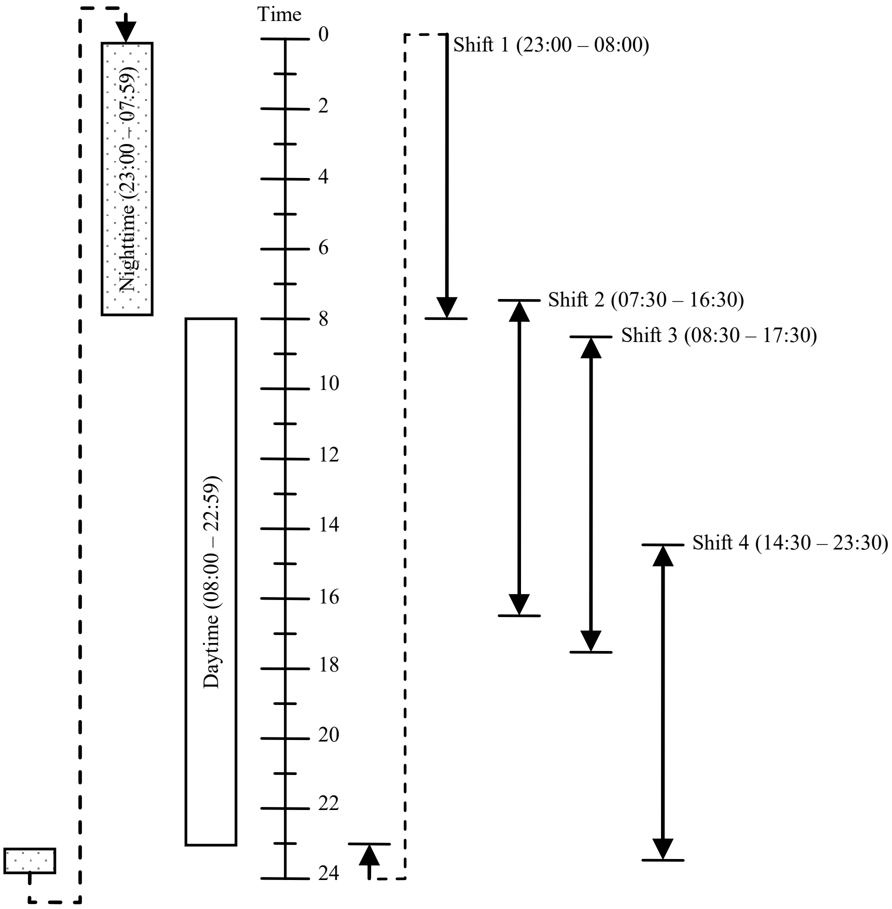

Figure 3 Delineation of the work shifts

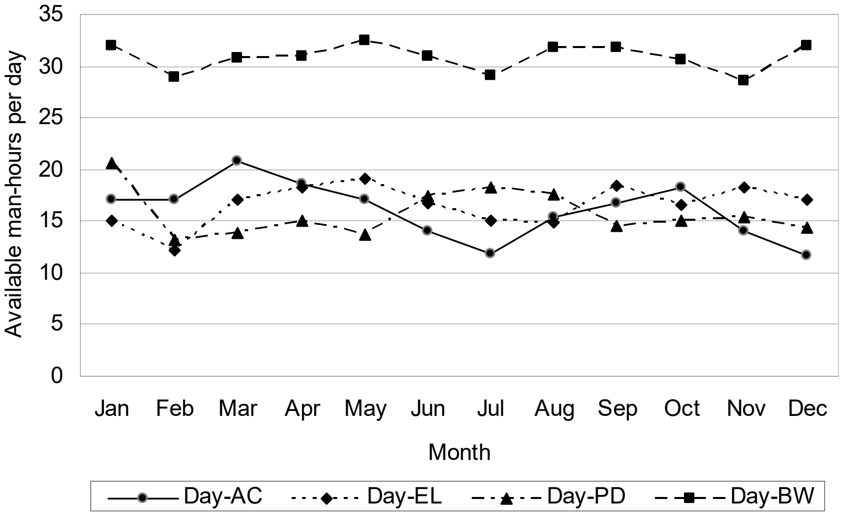

Figure 4 Variation of maintenance manpower input

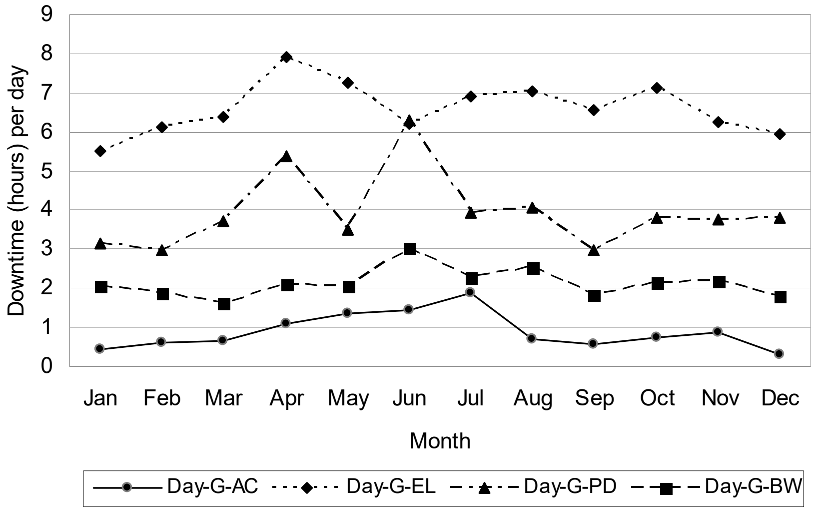

Figure 5 Variation of maintenance performance

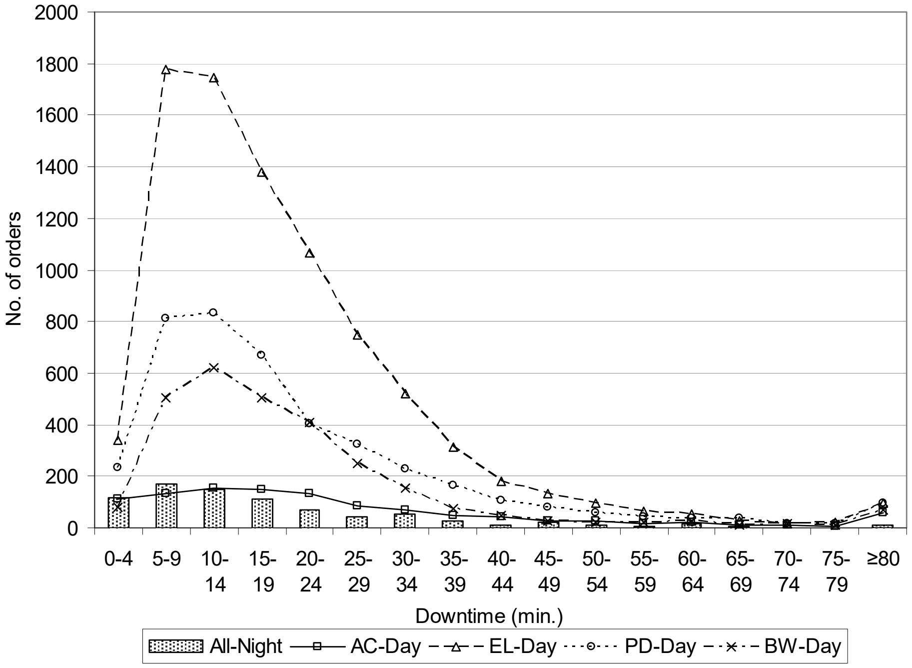

Figure 6 Distributions of the facilities' downtimes

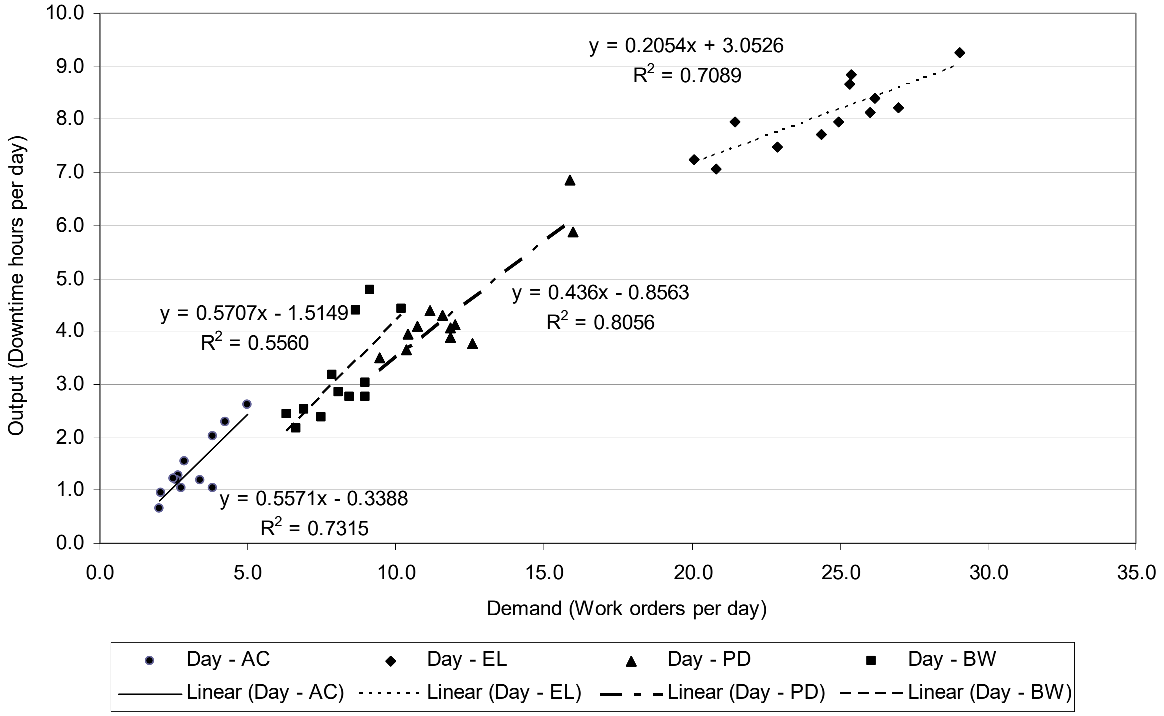

Figure 7a Relationship between maintenance output and maintenance demand

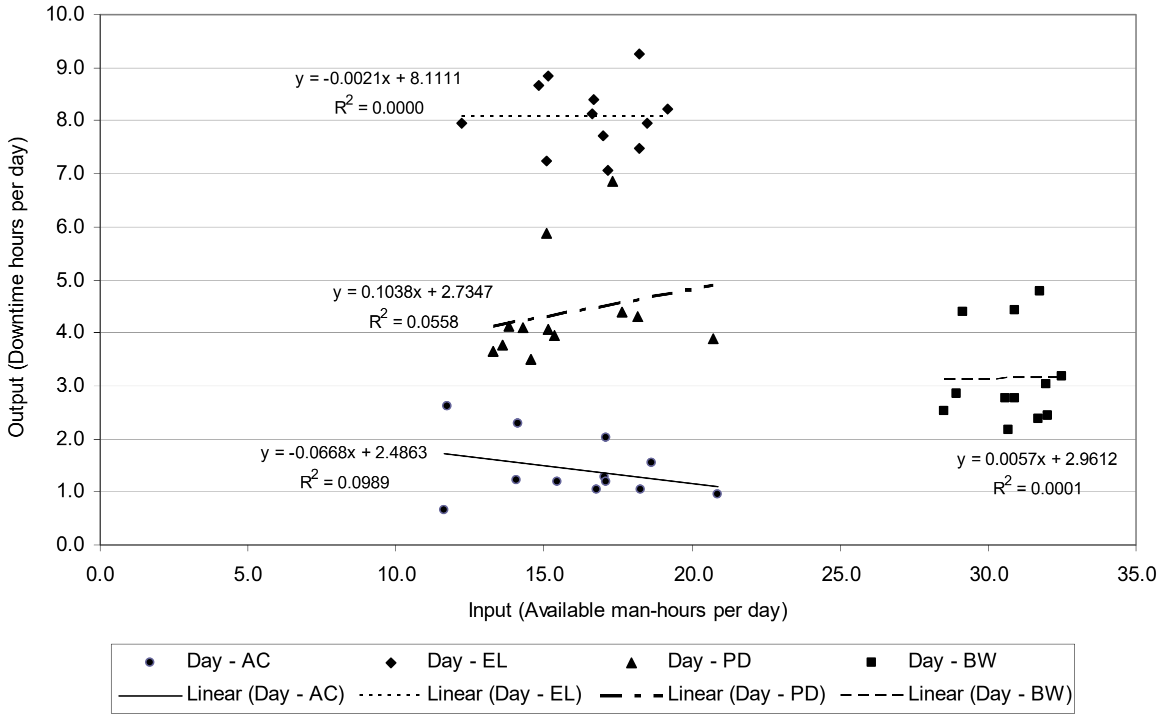

Figure 7b Relationship between maintenance output and maintenance input