Developing a Model for the Optimization of Maintenance Costs in Commercial Buildings in UAE

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Abstract

Maintenance operations refer to the set of activities required to replace a component, or a group of components subjected to wear and tear in a system, asset or machine. Among such maintenance operations, preventive maintenance plays an important role for its proactive effect on the serviceability of components in a system. Scheduling of preventive maintenance is a critical operation in maintenance and reliability engineering which helps construct proactive programs to improve the operating condition of assets and extend their service life. In its general settings, the partners of asset include (i) the asset vendor (ii) the asset user and (iii) the service maintenance provider. While such assumptions focus on durability, however, they do not guarantee cost optimal solutions. In contrast to the above assumptions, the aim of this study is to present an original Mixed Integer Linear Programming model (MILP) of cost-based scheduling. Here, different resources and reliability functions will be considered in the model. The model also tends to reduce the overall cost function of spare parts contributions, the cost of implementing preventive measures and the cost of additional repair activities considering the staff efficiency that is monitored and controlled using latest efficient technology. The study will present a detailed solution and discussion of the model and the related decision variables. Comparisons between the existing schedules and the proposed ones may be considered along with targeted sensitivity analysis.

Keywords
Optimization, Scheduling problem, Corrective Maintenance, Preventive Maintenance, Reliability Engineering.

1. Introduction

It is becoming extremely important to manage the cost of maintenance specially in commercial buildings in UAE due to high manpower cost and facilities management contracts that are controlled by high efficiency and quality maintenance for different electromechanical systems feeding those buildings and facilities. In order to reduce the cost of the maintenance and better utilize the resources that achieve the required service agreement and maintenance quality, maintenance companies need to seek better maintenance models to cope with the persistent customer requirements and increasing cost burden. Optimization models can significantly improve maintenance performance subject to limited budgets and capacities. An optimization approach needs to be captured to consider the optimum maintenance cost and quality measures that reduce the cost of the facilities management service providers and the cost incurred by the clients. The model will be tested by a case study of a well-known commercial building in UAE which consists of a variety of electro-mechanical systems that experienced different maintenance activities in the year 2018. The targeted results are the optimum schedule of maintenance tasks and cost taking into consideration that the maintenance service level achieved as per the contractual terms.

1.1 Definitions and Terminology

This section presents the definitions of the terms used in this paper. Further details are presented to explain the types of maintenance, parties of the maintenance contracts, assets involved in the maintenance and tools used to monitor the efficiencies.

- **Maintenance cost per asset (MC):** the cost per maintenance activity per system type over the maintenance frequency.
- **Preventive Maintenance (PM):** Preventive maintenance (or planned maintenance): the items included in this category are those scheduled for predefined, regular intervals to ensure the component's continued good performance; this type of maintenance reduces non-planned works and allows the estimation of overall costs (Colenm & Brito 2010).
- **Corrective (reactive) Maintenance (CM):** This is associated with the correction of unexpected anomalies and is almost always an emergency procedure, leading to unavoidable extra costs; it is important to standardize technical procedures that allow the minimization of the drawbacks of this type of maintenance (Colenm & Brito 2010).
- **Predictive Maintenance (PDM):** Predictive maintenance (or condition-based maintenance) by performing inspection planning: the predictions involved in this type of maintenance show an important capacity for improved accuracy.
- **Asset Size (A):** identifies the number of assets involved under each system category.
- **Staff Manhours (Mh):** manhours spent by each staff to perform specific maintenance activity in specific system.
- **Air conditioning systems (ACs)**: Cooling or heating air temperature treatments and control systems.
- **Electrical systems (ES):** Electrical distribution panels and components used in commercial buildings.
- **Plumbing systems (PL):** Water distribution networks, as water providing systems.
- **Civil works (CV:** masonry, carpentry and painting works.
- **PDA:** A personal digital assistant (PDA), also known as a handheld PC, is a variety mobile device which functions as a personal information manager. PDAs were largely discontinued in the early 2010s after the widespread adoption of highly capable smartphones, in particular those based on iOS and Android (Smith & Wempen 2011).

2. Literature Review

In this section, a thorough exploration of previous studies in the field of maintenance is considered. The section separates the literature into six subsections.

2.1 Maintenance's Efficiency Monitoring and Improvements

Maintenance efficiency has been considered in literature of scheduling problems related to maintenance activities. For instance, according to Murthy, Karim and Ahmadi (2015) the tasks performed by technicians and the work force performance are both impacting the cost in the maintenance companies. A plant maintenance problem studied by Liu and Yu Sun (2004). In their research, the authors explored that the accurate and logical evaluation of plant maintenance will allow the enterprise to distinguish among the most appropriate performed maintenance pattern. A problem of scheduling the maintenance between two telecommunication nodes over time in the available network has been investigated by (Abed et al. 2009). It aims to reduce interruptions in the networks of telecommunications. An approach to address the problem of improving selective maintenance in a multi-component system discussed by Khatab and Aghezzaf (2016). The system under study performs different tasks under dedicated scheduled intervals. A case study to determine the maintenance budget of government owned buildings discussed by (Mohd-Noor et al. 2011). A risk-based optimal strategy for managing assets' preventive maintenance tasks and resource allocation discussed by (Li et al. 2006). Three hierarchical decision problems are addressed: total resource planning for maintenance, resource allocation to maintenance categories and task selection within each category. Building maintenance operation processes with respect to maintenance strategy, acceptable standard and resources have been discussed in (Lee & Scott 2009). Different maintenance optimization model while focusing on criteria and objectives been reviewed in the literature been reviewed by (Van, Pintelon & Muchiri, 2010).

2.2 The use of technologies For Maintenance Scheduling Problems

The use of technologies has been discussed in literature to tackle the maintenance scheduling problems. In his work, Khatab et al. (2018) examines a new variant of selective maintenance optimization problem for a multi-component system where more than one channel is supposed to fix a component. A resource optimization approach for transmission system maintenance been studied by (Jiang, McCalley, & Van-Voorhis, 2006). The problem discussed is a selection and scheduling problem that is based on the cumulative long-term risk caused by failure of each piece of equipment. A simulated annealing algorithm with parallel architecture, so-called multi-threading simulated annealing (MTSA), proposed to solve a bi-objective maintenance scheduling problem with a multi-skilled workforce constraint (Safaei, Banjevic & Jardine, 2012). Conflicting objectives were considered: the minimization of the total equipment downtime caused by maintenance jobs and the minimization of the multi-skilled workforce requirements over the given horizon. A modeling of the multiple knapsack problem, with a mechanism for allocating resources called Lago Allocator addressed the issue of energy saving. An algorithm based is then proposed on ant colony to solve this problem (Amarante et al. 2013). A scheduling algorithm which leverages Condition-Based Maintenance (CBM) data to determine when maintenance should be performed has been presented (Reimann et al. 2009). A framework developed by Chen et al. (2018) to automatically schedule maintenance tasks using single team based on building information modeling (BIM). A service management 4.0 concept been based to develop a framework to interlace technologies with providing services to products after sales Kans and Ingwald (2016). Different way of treating scheduling problem through the use of building occupants' satisfaction to develop an agent-based model was studied by (Cao, Wang & Song, 2015). Response time found to be the major influence on the occupant satisfaction and the scheduling of maintenance setup according to it. A scheduling problem for integrated maintenance of power generation and transmission systems considering common uncertainties was studied by El-Sharkh and El-Keib (2003). A preventive maintenance scheduling problem introduced by (Budai, Huisman & Dekker,2006) for train railway in Netherlands. Gholami and Hafezalkotob (2018) discussed Condition-based maintenance (CBM) scheduling problem to determine when and which maintenance activities should be performed to a pump. A combination of data mining techniques and time series models to schedule maintenance activities presented.

2.3 Mathematical Optimization Models

Mathematical optimization models have been presented in different articles. Models of non-linear integer programming have been established to solve the size of the workforce in a maintenance problem with the objective of improving productivity (Ighravwe & Oke 2014). The problem of enhancing the maintenance for a system with multiple components has been addressed by Khatab et al. (2018). A Mixed Integer Linear Programming model (MILP) proposed by Manzini et al. (2015) to tackle cost, assets' reliabilities and resources constraints for scheduling of preventive maintenance measures. Other research proposed a bi objected optimization model for an aircraft maintenance works in such a way to minimize the total maintenance cost and taking into account the tasks allocation based on workload (Chen et al. 2017). A Tabu based heuristic algorithm is developed to obtain Pareto efficient solutions. A proposed scheduling problem for adaptive preventive maintenance (PM) approach that increases net savings from PM with constraint of workforce size was studied by (Gopalakrishnan, Ahire & Miller, 1997). The authors' approach consists of two components: (a) prioritizing the task based on a multiple logarithmic regression model for each type of PM task, and (b) rescheduling tasks based on a binary integer programming model (BIP) subject to an individual and multiple workforce skills availability. A mixed-integer linear model incorporating flexible and diverse maintenance activities for minimizing total tardiness and maintenance costs in a permutation flow shop scheduling discussed (Yu & Seif 2016). A planned preventive maintenance scheduling problem modeled and a Tabu search-based heuristic used as adaptive memory procedure at different manufacturers of United Technologies Corporation operations (Tang, Miller-Hooks & Tomastik, 2007). A bilevel approach used by Naebi et al. (2018) to model a preventive maintenance scheduling problem for a single producer of power generating units. An optimization model of the maintenance problem of a military craft presented as a mixed- integer mathematical programming model in which the network flow structure is used to simulate the flow of aircraft between missions, hanger and repair shop (Safaei, Banjevic, & Jardine, 2011). Another scheduling problem discussed by Rey et. al (2019) to find an optimal schedule for the coordination of road maintenance projects in a transport network over a planning period. A Mixed integer programming model to solve the scheduling problem of train and rail network maintenance studied by Lidén and Joborn (2017).A new maintenance policy for vehicle maintenance proposed by (Mallouk, El Majd & Sallez, 2018) based on multi-objective optimization model. A Bi Objective Mixed-Integer Linear Programming (BOMILP) model developed by Golpîra and Tirkolaee (2019) to incorporate Robust Optimization (RO) concept into the maintenance and repair tasks scheduling problem.

2.4 Heuristics Maintenance Scheduling Problems

A failure mode effect analysis (FMEA) modification policy used to determine maintenance errors for possible tests (Zhang et al. 2017). A genetic algorithm used to approximate the best maintenance plan of building façade related components (Paulo et al. 2016). A scheduling problem to distribute a set of railways' maintenance tasks in Jutland for a set of maintenance team studied by (Pour, Drake & Burke, 2018). Two main considerations were considered: the equal distribution of tasks among the team and equal traveling distances that to be minimized to execute the tasks between the subregions. The literature concerning about multicriteria scheduling problems which are involving two or more sets of jobs was reviewed by (Perez-Gonzalez & Framinan 2014). Where an analysis been carried out of the studied literature about the topic, it was found that the most suitable name for multicriteria scheduling problems is interfering jobs scheduling problem. A test task scheduling problem (TTSP) has been discussed by (Lu et al. 2014). Although it is a problem with NP-complete problem. The main advantage of TTSP is the close interactions between task sequences and schema selection. In their study Burke and Smith (2000) explained a new approach of inputting the local search operators into a genetic algorithm for a scheduling problem of thermal generator maintenance. A fuzzy multiple criteria decision making (MCDM) evaluation method used to evaluate the most popular maintenance approaches namely, strategies, policies, or philosophies Al-Najjar and Alsyouf (2003). It was found that the most cost-effective maintenance approach is where failure causes of the machine caused by quality, machine condition and environment are known. In their work Altuger and Chassapis (2009) proposed a multi criteria decision making approach to select the preventive maintenance schedule that gives the optimum utility and performance values in the case of a line productivity. A preventive maintenance planning problem for high speed trains in China discussed by Lin et al. (2019). The problem represented as a programming model of 0-1 as a function to present whether or not the train is under maintenance. A methodology presented by Camci (2015) to schedule the maintenance of geographically distributed assets as off-shore wind farms and railway switches using their prognostic information. An optimization model is used to minimize the maintenance costs and traveling distances between the assets.

2.5 Mixed Optimization Models and Heuristic Maintenance Scheduling Problems

A cost-based selective maintenance decision-making method used for a selected set of manufacturing machines with defined maintenance intervals while the reliability is a concern studied by (Zhu et al. 2011). An adaptive scheduling with quality of service (QoS) satisfaction algorithm model for the hybrid cloud environment to raise the resource utilization rate of the private cloud and to diminish task response time as much as possible proposed by (Wang et al. 2013). The optimization approach considered the allocation in the private cloud that reduce the number of tasks on the public cloud. An optimization approach along with predictive algorithm to improve the railway maintenance discussed the European Commission's 7th Framework Program (Jimenez–Redondo et al. 2012). An improvement model that targets the relationship between maintenance activities and reliability in energy facilities in Brazil was proposed by (Usberti et al. 2015). Two criteria were taken into account: the cost of maintenance activities and the maximum value of the average frequency indicator system outage for the maintenance planning period. In their article, Sun and Li (2010) presented the relation of processing a set of jobs on two identical parallel machines. Two scheduling models are considered: (1) The maintenance activities are performed periodically, and the objective is to schedule the jobs on two machines such that the manufacturing span is minimized. (2) The maintenance activities are determined jointly with the scheduling of jobs, and the objective is to minimize the total completion time of jobs. Bin-packing problem and Heuristic algorithm where used to model the optimization problem. A scheduling task of machines perform independent tasks and configured with different profiles. Each machine is supposed to be monitored and a prognostic module gives its remaining useful life depending on both its past and future usage (Nicod, Obrecht & Varnier, 2013). The objective is to configure the platform to reach the demand as long as possible. The time discretized into periods and to choose a configuration for each period. An Integer Linear Programming (ILP) model to find such configurations for a fixed time horizon. Guo et al. (2011) discussed maintenance scheduling problem of grid services which have large subtasks.

2.6 Reviewed Articles about Scheduling Maintenance Problems

A set of reviewed articles where considering the multi-resource generalized assignment problem (MRGAP) been studied by (Alidaee, Gao & Wang, 2010). The carried-on literature review by the authors was to present an assignment model that compile the models in the previous research papers. They proposed a model defined as a generalization of MRGAP (GMRGAP). According to Fraser (2014), a study of 37 articles about different maintenance management model was presented. Four basic models identified such as: total productive maintenance (TPM), condition-based maintenance (CBM), reliability-centered maintenance (RCM), and condition monitoring (CM). A review of literature conducted by Froger et al. (2016) for maintenance models of power plants and transmission lines in the electricity industry. The literature been reviewed to synthesize and categorize the published literatures related to maintenance strategies formulation, selection and implementation in various industries by Velmurugan and Dhingra (2015).

3. Asset Failure Analysis

A matter of fact that is encountered in every aspect of life, is that things fail. There is no item, equipment, product, etc., that last forever. This leads to the need for understanding the lifetimes of assets. Reliability engineering is the discipline that studies lifetimes and failure modes of components. In general, since randomness does exist in the lifetimes, probability distributions were exceptionally adequate in modeling the operational lifetimes of equipment until their first/subsequent failures, repair or replacement. The Exponential, Weibull and Normal distributions were heavily used in modeling the operational life of equipment/components. The analysis of repair and replacement has been well explored in the literature too. Repairs can be done either in a preventive manner (i.e., before the occurrence of the failure) or correctively (after the failure).

Upon repair, the equipment under consideration is either back to its last working state (minimal repair) or as-good-as new, where in this case the reliability is significantly improved. Figure 1 shows a given distribution of the lifetime of a standard bearing of an increasing failure rate $\lambda(t)$. The reliability is the probability that the lifetime exceeds a specific age, which is given by $R(t)$, where $R(t) = 1 - F(t) = \int_t^{\infty} f(t)\,dt$ and $F(t)$ is the cumulative distribution of the lifetime distribution $f(t)$. The mean time to failure *MTTF* is the mean of $f(t)$, which can be easily estimated for some distributions, that is: $MTTF=\int_0^{\infty} t.f(t)\,dt$

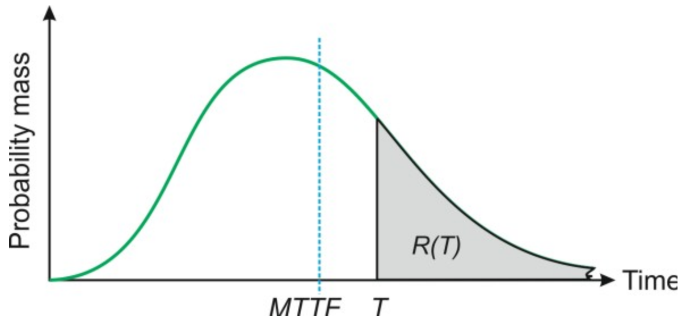

Figure 1. Lifetime distribution.

In preventive maintenance, the reliability function is constructed upon the assumption that the equipment could survive to the preventive maintenance time, where in this case the reliability, even for as-good-as-new case, is under the condition of survival to the moment of maintenance, hence the reliability never gets back to 100%. In fact, for lifetimes of exponential distributions, preventive maintenance is worthless. In this paper, maintenance tasks of equipment/components will be assigned to workers in specific calendar days within a planning period. For each equipment, the lifetime distribution is supposed to be given, where piecewise shape may be used to simplify the analysis. Two maintenance scenarios may arise, first, the stochastic cost of maintenance if the maintenance activity is assigned before the *MTTF* of an equipment, second, the stochastic cost if the maintenance is assigned after the *MTTF*. To estimate such cost scenarios, the failure rates before and after *MTTF* should be investigated. To start with, we may begin by assuming some constant failure rates for each equipment/task, say i. If the maintenance task is assigned at time L, where $L \geq MTTF$ then the task is late by the amount of *L-MTTF*, otherwise, if the task is conducted before *MTTF*, then it is early by *MTTF-E*. If the average failure rate is estimated for the period from the beginning of the asset life till the *MTTF*, called λ_e and that of after the *MTTF* to the end of the lifetime called λ_L and denoting the corrective cost by C, then the stochastic cost component for early maintenance is $\lambda_e \times (MTTF - E)C$, similar component can be estimated for late assignment of the task, that is: $\lambda_L \times (L - MTTF)C$. Figure 2 demonstrates the concept of two failure rate averages for an increasing failure rate function.

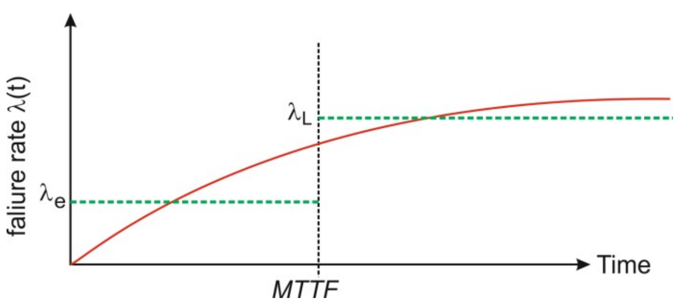

Figure 2. Increasing failure rate (in red).

By assigning tasks for a system of multiple components and multiple workers for each task in each day, the problem gets more complicated. Moreover, the travel distance between the tasks may consume significant time out of that available each day for each repair man, by reorganizing (scheduling) the tasks using the suitable sequence, both the time and cost can be reduced.

The smart tools used generates a very useful data per worker category. This data is shaping the time consumed per worker category to attend specific task either with preventive or corrective maintenance performed works. Table 1 explains one month generated data through PDA:

Table 1. Monthly records of workers PPM & CM tasks

Worker Description	% of time Records More than 4 (Hour)	Count of time Records More than 9 (Hour)	PPM Time (Hour)	CM Time (Hour)	Adjusted Total Time (Hour)
Tec-HVAC-1	0.0	0.0	0.0	0.2	102.2
Tec-HVAC-2	3.6	0.0	4.1	24.3	321.8
Tec-HVAC-3	1.0	4.0	454.2	0.0	454.2
Tec-HVAC-4	26.7	2.0	0.0	231.3	231.3
Tec-HVAC-5	3.6	4.0	0.0	267.0	267.0
Tec-HVAC-6	8.2	9.0	0.0	150.2	150.2
Tec-HVAC-7	5.7	4.0	0.0	275.7	275.7
Tec-Electrician-1	2.5	2.0	0.0	18.5	265.2
Tec-Electrician-2	0.0	0.0	215.8	0.0	215.8
Tec-Electrician-3	5.8	8.0	0.0	282.7	282.7
Tec-Electrician-4	0.0	0.0	8.5	12.2	312.4
Tec-Electrician-5	0.0	0.0	0.0	0.1	0.1
Tec-Electrician-6	0.4	1.0	1.0	155.6	156.6
Tec-Mechanical-1	0.9	3.0	335.4	0.0	335.4
Tec-Mechanical-2	0.9	0.0	0.0	219.6	219.6
Tec-Mechanical-3	69.2	8.0	0.0	248.2	248.2
Tec-Plumber-1	5.8	5.0	1.0	230.9	231.9
Tec-Plumber-2	2.0	0.0	1.5	298.1	299.6
Tec-Plumber-3	0.0	0.0	0.0	134.7	134.7
Tec-Pntr.Crpntr.Msn-1	18.3	3.0	0.0	213.1	213.1
Tec-Pntr.Crpntr.Msn-2	5.1	8.0	0.0	174.8	174.8
Tec-Pntr.Crpntr.Msn-3	2.2	1.0	0.0	236.9	236.9

4. Data Available

This section will present an overview about the detailed available data from the real case study that will be used as an input to our model. These data information will reflect the complexity of the model and a clear description what variables will be obtained from the model solution. The data consists of the maintainable assets as type of assets involved, size of each asset, number of preventive and corrective maintenance tasks, number of spare parts and failure rate of each asset category.

- AVG monthly corrective Tasks 150 Tasks.
- Monthly Preventive maintenance Tasks 200.
- Maintainable Spares AVG of 76 Spares distributed over assets categories as the table mentioned per month/3 months/6 months/ year.

It is worth noting to indicate the size of assets under the case study to be serviced. There are 1000 assets with different asset categories distributed in over 16 different locations as in the followings Table 2. It is worth noting that the data collected from a well-known maintenance service provider company in the UAE where a maintenance contract agreed between two parties. In case other data where will be required to complete the study are not shared, a specialist will be approached to get approximate data about the asset life, expecting running hours to failure and man hours to perform maintenance tasks in an efficient manner per asset given the geographical known distances.

Table 2. Asset details and Categories in Commercial Building Under Study

Asset Category	Item	Description	Quantity
Mechanical/Air Conditioning	1	Fans	70
	2	Fan Coil Units	432
	3	AHU	15
	4	Chilled Water Pumps	9
	5	Pumps	10
	6	Split AC Units	38
Electrical Systems	7	Main Distribution Board (MDB)	2
	8	Sub Main Distribution Board (SMDB)	32
	9	Control Boards (CB)	26
	10	Distribution Board (DB)	95
	11	Capacitor Bank Boards (CBB)	9
	12	Electric Water Heater (EWH)	194
Plumbing & Civil Assets	13	Water Fittings & Masonry, Marbles & Doors (PLCV)	68

5. Integer Linear Programming Model

Linear programming has been used to model the maintenance cost and optimum scheduling of maintenance activities of commercial buildings assets in the United Arab Emirates. The required maintenance quality for different types of assets, namely; Mechanical, Electrical, Plumbing (MEP) and Civil will be taking into consideration to be satisfied to the client. The objective function will minimize the cost that consists mainly of the cost of preventive and corrective maintenance activities. It is assumed a maintenance service provider offers a given set of maintenance tasks that will be performed on a frequent basis by a certain set of workers over a given planning period (called contract period). The planning period is measured in days where a worker k can perform a maintenance operation on asset i (i.e., task i) on a given day j. However, as a consequence of work, time and capacity limitations; different constraints may arise that will be discussed briefly in this section. Let the binary variable $s_{i,j,k}$ denote a selection variable, that is:

$$s_{i,j,k} = \begin{cases} 1, & \text{if task } i \text{ is assigned to operator } k \text{ on day } j \\ 0, & \text{otherwise} \end{cases}$$

The expected general form of the objective function includes two major cost components, i.e., the preventive and corrective maintenance costs. Let C_i^F be the fixed cost of conducting the maintenance task i and d_i the duration of the same task. If the labor cost of worker k is denoted by C_k^L, then the cost of scheduled maintenance can be given by $\sum_i^I \sum_j^J \sum_k^K (C_i^F + d_i C_k^L) s_{i,j,k}$ for a set of tasks I, a set of calendar days J and K workers, where, i , j, k are the indices of tasks, days and workers available to perform the maintenance plan, respectively. A general notion for the corrective maintenance cost is to consider the expected frequency of the corrective task. This leads to the consideration of the expected number of failures within the planning period that consists of J days, where in this case, the lifetime distribution should be addressed. If a constant failure rate along with "as-good-as-new" assumption is considered, then the number of repair tasks can be easily computed. Let λ_i denote the failure rate of equipment i, the number of failures in a period of t is thus given by $\lambda_i \times t$ and the associated expected cost is $\lambda_i \times t \times C_i^c$, where C_i^c is the cost of corrective maintenance of asset i. Under the assumption of constant failure rate in some period of the lifetime of an asset, let the mean time between failures of asset *i* be $MTTF_i$. If the failure of asset *i* occurs exactly at $MTTF_i$, then the corrective cost is given by $\lambda_i \times MTTF_i \times C_i^c$. Of note, $MTTF_i$ is just the average lifetime of asset *i* and the resulting cost is the average cost if the maintenance happens exactly at $MTTF_i$. However, in reality the maintenance may be scheduled before/after the mean time between failures. If maintenance happens earlier than $MTTF_i$, we call this as early repair, otherwise called late repair. Denote by $E_{i,j,k}$ the period of time between $MTTF_i$ and the time maintenance is carried out (when the maintenance happens before $MTTF_i$) and $L_{i,j,k}$ be the time period between the mean time and the time maintenance was carried out (if later than $MTTF_i$). Figure 3 demonstrates the idea.

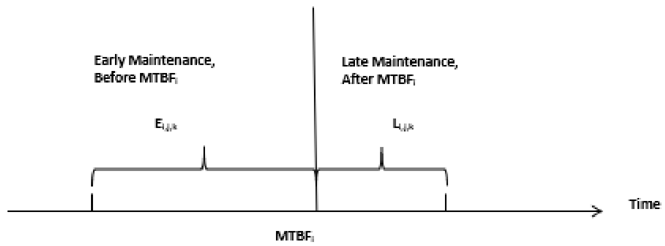

Figure 3. Early Maintenance VS Late Maintenance according to $\boldsymbol{MTTF_i}$.

Accordingly, if the repair is performed earlier than $MTTF_i$ then the corrective cost is $\lambda_e \times (MTTF_i - E_{i,j,k}) \times C^c$. Similarly, if the maintenance task is performed after $MTTF_i$, then the corrective maintenance cost is: $\lambda_L \times (MTTF_i + L_{i,j,k}) \times C^c$. Note that only one variable of ($E_{i,j,k}$ and $L_{i,j,k}$) will have a positive value while both can have a zero value if the repair is scheduled exactly at $MTTF_i$. This condition will be added in the set of constraints. To this end, a general objective function is:

$$\min \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \left((C_i^F + d_i C_k^L) s_{i,j,k} + \lambda_e \times \left(MTTF_i - E_{i,j,k}\right) \times C_i^c + \lambda_L \times \left(MTTF_i + L_{i,j,k}\right) \times C_i^c \right)$$

The above expression will represent the general form of the objective function that will be employed in this paper. The set of constraints will include different types that are associated with the available capacities, working days, tasks, labor, etc. Some of the constraints that will be considered may include the following: Each task is assigned to a specific worker within the period of the contract (the planning period). While a task can be performed multiple times within a planning period (for preventive or corrective maintenance) the task can only be performed by the same worker. By this, workers hands-on can be allocated to serve higher level of specialty. This can be modeled as $\sum_{k=1}^{K} TW_{i,k} = 1$, where $TW_{i,k}$ is the Task-Worker binary matrix that allocates 1 if task *i* is assigned to worker *k* and 0 otherwise. This formulation states that task *i* is done by only some worker *k*, however, to make sure that the task *i* is performed by the same worker through all the available days whenever it is required, another constraint is needed. That is: $\sum_{j=1}^{J} s_{i,j,k} \leq M \times TW_{i,k}$, where M is a very large positive number. A capacity constraint that may be considered is the time availability. The working time may differ among the workers due to regular and overtime policies. The available work time differs by day and workers. Some workers may prefer to put more working hours in specific days, a matter which creates different daily work capacities. This can be modeled as $\sum_{i=1}^{I} \left(d_i s_{i,j,k} + S_i \times \sum_{k=1}^{K} s_{i,j,k}\right) \leq Cap_{j,k}$, where S_i is the setup time to get prepared for task *i* and $\sum_{k=1}^{K} s_{i,j,k}$ refers to the allocation of task *i* to day *j*; this quantity=1 if the task is assigned to day *j* and "0" otherwise. The available time capacity of worker *k* on day *j* is given by $Cap_{j,k}$.

5.1 Sensitivity Analysis

Sensitivity Analysis deals with finding out the amount by which the input data can be changed for the output of a linear programming model to remain comparatively unchanged. This helps in determining the sensitivity of the data added to the problem. If a small change in the input (for example in the change in the availability of some raw material) produces a large change in the optimal solution for some model, and a corresponding small change in the input for some other model doesn't affect its optimal solution as much, so it can be concluded that the second problem is more robust then the first. The second model is less sensitive to the changes in the input data. A case will be considered where there is a sensitivity of the optimum solution to the changes in the availability of resources. (Right hand side of the constraints.) If in any linear programming problem, there are *n* variables and *m* constraints and the right-hand sides as being the representatives of the amount of resources. As a conclusion, sensitivity analysis reflects how does the optimal solution change as some of the elements in the model change, such as right-hand side (RHS), coefficient matrix (LHS) or signs (=, ≤,≥).

6. Conclusion

This study discusses the framework to build research that is having an objective of selective maintenance problem for commercial buildings in the United Arab Emirates. An optimization model to minimize the incurred maintenance costs by solving scheduling problem for workforce assignments and priority of tasks is performed. Traveling distances and work force allocation as per task priority to be considered in order to reduce the overall time frame of the maintenance period in the preventive and corrective maintenance tasks. The model requires to set a platform for the maintenance companies in order to properly manage budgeting maintenance contracts for different types of clients for either commercial or residential premised in anywhere. By reducing the different cost components and establishing better schedules, maintenance contracts can be prepared sensibly for better competition in market bids. The problem under study is to schedule a maintenance task for assets in buildings in such away the overall maintenance cost incurred by the service provider per task is minimized over the contract period. The expected results may participate in reducing the expenses on the service provider in reduction of required workers' size to perform the maintenance tasks of assets as required service level. This will enrich the knowledge of the way of providing the service by the service providers to perform the assets maintenance tasks with lower cost and hence focus on improving the maintenance strategy by the insertion of smart technologies for better maintenance service delivery.

References

Abed, F., Chen, L., Disser, Y., Groß, M., Megow, N., Meißner, J., Richter, A.T. and Rischke, R., 2019. Scheduling maintenance jobs in networks. Theoretical Computer Science, 754, pp.107-121.

Aghezzaf, E.H., Jamali, M.A. and Ait-Kadi, D., 2007. An integrated production and preventive maintenance planning model. European journal of operational research, 181(2), pp.679-685.

AI Multiple. (2019, October 14). Retrieved from https://blog.aimultiple.com/predictive-maintenance-vs- preventive-maintenance/Lindo Systems (2019, Dec 29). Retrieved from: https://www.lindo.com/index.php/contact

Al-Najjar, B. and Alsyouf, I., 2003. Selecting the most efficient maintenance approach using fuzzy multiple criteria decision making. International journal of production economics, 84(1), pp.85-100.

Altuger, G. and Chassapis, C., 2009, December. Multi criteria preventive maintenance scheduling through arena-based simulation modeling. In Winter Simulation Conference (pp. 2123-2134). Winter Simulation Conference.

Alidaee, B., Gao, H. and Wang, H., 2010. A note on task assignment of several problems. Computers & Industrial Engineering, 59(4), pp.1015-1018.

Amarante, S.R.M., Roberto, F.M., Cardoso, A.R. and Celestino, J., 2013, December. Using the multiple knapsack problem to model the problem of virtual machine allocation in cloud computing. In 2013 IEEE 16th International Conference on Computational Science and Engineering (pp. 476-483). IEEE.

Budai, G., Huisman, D. and Dekker, R., 2006. Scheduling preventive railway maintenance activities. Journal of the Operational Research Society, 57(9), pp.1035-1044.

Burke, E.K. and Smith, A.J., 2000. Hybrid evolutionary techniques for the maintenance scheduling problem. IEEE transactions on power systems, 15(1), pp.122-128.

Camci, F., 2015. Maintenance scheduling of geographically distributed assets with prognostics information. European Journal of Operational Research, 245(2), pp.506-516.

Cao, Y., Wang, T. and Song, X., 2015. An energy-aware, agent-based maintenance-scheduling framework to improve occupant satisfaction. Automation in Construction, 60, pp.49-57.
Chen, G., He, W., Leung, L.C., Lan, T. and Han, Y., 2017. Assigning licenced technicians to maintenance tasks at aircraft maintenance base: a bi-objective approach and a Chinese airline application. International Journal of Production Research, 55(19), pp.5550-5563.
Chen, W., Chen, K., Cheng, J.C., Wang, Q. and Gan, V.J., 2018. BIM-based framework for automatic scheduling of facility maintenance work orders. Automation in Construction, 91, pp.15-30.
El-Sharkh, M.Y. and El-Keib, A.A., 2003. Maintenance scheduling of generation and transmission systems using fuzzy evolutionary programming. IEEE Transactions on Power Systems, 18(2), pp.862-866.
Fraser, K., 2014. Facilities management: the strategic selection of a maintenance system. Journal of Facilities Management, 12(1), pp.18-37.
Froger, A., Gendreau, M., Mendoza, J.E., Pinson, E. and Rousseau, L.M., 2016. Maintenance scheduling in the electricity industry: A literature review. European Journal of Operational Research, 251(3), pp.695- 706.
Gholami, P. and Hafezalkotob, A., 2018. Maintenance scheduling using data mining techniques and time series models. International Journal of Management Science and Engineering Management, 13(2), pp.100- 107.
Guo, S., Huang, H.Z., Wang, Z. and Xie, M., 2011. Grid service reliability modeling and optimal task scheduling considering fault recovery. IEEE transactions on reliability, 60(1), pp.263-274.
Lidén, T. and Joborn, M., 2017. An optimization model for integrated planning of railway traffic and network maintenance. Transportation Research Part C: Emerging Technologies, 74, pp.327-347.
Lin, B., Wu, J., Lin, R., Wang, J., Wang, H. and Zhang, X., 2019. Optimization of high-level preventive maintenance scheduling for high-speed trains. Reliability Engineering & System Safety, 183, pp.261-275.
Rey, D., Bar-Gera, H., Dixit, V.V. and Waller, S.T., 2019. A Branch-and-Price Algorithm for the Bilevel Network Maintenance Scheduling Problem. Transportation Science.
Golpîra, H. and Tirkolaee, E.B., 2019. Stable maintenance tasks scheduling: A bi-objective robust optimization model. Computers & Industrial Engineering, 137, p.106007.
Gopalakrishnan, M., Ahire, S.L. and Miller, D.M., 1997. Maximizing the effectiveness of a preventive maintenance system: an adaptive modeling approach. Management Science, 43(6), pp.827-840.
Ighravwe, D.E. and Oke, S.A., 2014. A non-zero integer non-linear programming model for maintenance workforce sizing. International Journal of Production Economics, 150, pp.204-214.
Jiang, Y., McCalley, J.D. and Van Voorhis, T., 2006. Risk-based resource optimization for transmission system maintenance. IEEE Transactions on Power Systems, 21(3), pp.1191-1200.
Jimenez–Redondo, N., Bosso, N., Zeni, L., Minardo, A., Schubert, F., Heinicke, F. and Simroth, A., 2012. Automated and Cost Effective Maintenance for Railway (ACEM–Rail). Procedia-Social and Behavioral Sciences, 48, pp.1058-1067.
Kans, M. and Ingwald, A., 2016. Business model development towards service management 4.0. Procedia CIRP, 47, pp.489-494.
Khatab, A. and Aghezzaf, E.H., 2016. Selective maintenance optimization when quality of imperfect maintenance actions are stochastic. Reliability Engineering & System Safety, 150, pp.182-189.
Khatab, A., Diallo, C., Venkatadri, U., Liu, Z. and Aghezzaf, E.H., 2018. Optimization of the joint selective maintenance and repairperson assignment problem under imperfect maintenance. Computers & Industrial Engineering, 125, pp.413-422.
Lee, H.H.Y. and Scott, D., 2009. Overview of maintenance strategy, acceptable maintenance standard and resources from a building maintenance operation perspective. Journal of building appraisal, 4(4), pp.269- 278.
Li, Y., Yeddanapudi, S., McCalley, J.D., Chowdhury, A.A. and Jewell, W., 2006, June. Resource management for distribution system maintenance using optimized risk reduction. In 2006 International Conference on Probabilistic Methods Applied to Power Systems (pp. 1-6). IEEE.
Liu, J. and Yu, D.J., 2004. Evaluation of plant maintenance based on data envelopment analysis. Journal of Quality in Maintenance Engineering, 10(3), pp.203-209.
Lu, H., Liu, J., Niu, R. and Zhu, Z., 2014. Fitness distance analysis for parallel genetic algorithm in the test task scheduling

problem. Soft Computing, 18(12), pp.2385-2396.

Mallouk, I., El Majd, B.A. and Sallez, Y., 2018. Optimization of the maintenance planning of a multi- component system. In MATEC Web of Conferences (Vol. 200, p. 00011). EDP Sciences.

Manzini, R., Accorsi, R., Cennerazzo, T., Ferrari, E. and Maranesi, F., 2015. The scheduling of maintenance. A resource-constraints mixed integer linear programming model. Computers & Industrial Engineering, 87, pp.561-568.

Misra, K.B. ed., 2008. Handbook of performability engineering. Springer Science & Business Media.

Mohd-Noor, N., Hamid, M.Y., Abdul-Ghani, A.A. and Haron, S.N., 2011. Building maintenance budget determination: an exploration study in the Malaysia government practice. Procedia Engineering, 20, pp.435-444.

Murthy, D.N.P., Karim, M.R. and Ahmadi, A., 2015. Data management in maintenance outsourcing. Reliability Engineering & System Safety, 142, pp.100-110.

Naebi Toutounchi, A., Seyed Shenava, S.J., Taheri, S.S. and Shayeghi, H., 2018. MPEC approach for solving preventive maintenance scheduling of power units in a market environment. Transactions of the Institute of Measurement and Control, 40(2), pp.436-445.

Nicod, J.M., Obrecht, L. and Varnier, C., 2013. Task scheduling to extend platform useful life using prognostics. IFAC Proceedings Volumes, 46(9), pp.134-139.

Paulo, P., Branco, F., de Brito, J. and Silva, A., 2016. Buildings Life–The use of genetic algorithms for maintenance plan optimization. Journal of cleaner production, 121, pp.84-98.

Perez-Gonzalez, P. and Framinan, J.M., 2014. A common framework and taxonomy for multicriteria scheduling problems with interfering and competing jobs: Multi-agent scheduling problems. European Journal of Operational Research, 235(1), pp.1-16.

Pour, S.M., Drake, J.H. and Burke, E.K., 2018. A choice function hyper-heuristic framework for the allocation of maintenance tasks in Danish railways. Computers & Operations Research, 93, pp.15-26.

Reimann, J., Kacprzynski, G., Cabral, D. and Marini, R., 2009. Using condition-based maintenance to improve the profitability of performance based logistic contracts. In Annual Conference of the Prognostics and Health Management Society (Vol. 2009, pp. 1-9).

Safaei, N., Banjevic, D. and Jardine, A.K., 2011. Workforce-constrained maintenance scheduling for military aircraft fleet: a case study. Annals of Operations Research, 186(1), pp.295-316.

Safaei, N., Banjevic, D. and Jardine, A.K., 2012. Multi-threaded simulated annealing for a bi-objective maintenance scheduling problem. International Journal of Production Research, 50(1), pp.63-80.

Sun, K. and Li, H., 2010. Scheduling problems with multiple maintenance activities and non-preemptive jobs on two identical parallel machines. International Journal of Production Economics, 124(1), pp.151-158.

Taha, H.A., 2013. Operations research: an introduction. Pearson Education India.

Tang, H., Miller-Hooks, E. and Tomastik, R., 2007. Scheduling technicians for planned maintenance of geographically distributed equipment. Transportation Research Part E: Logistics and Transportation Review, 43(5), pp.591-609.

Usberti, F.L., Lyra, C., Cavellucci, C. and González, J.F.V., 2015. Hierarchical multiple criteria optimization of maintenance activities on power distribution networks. Annals of Operations Research, 224(1), pp.171- 192.

Van Horenbeek, A., Pintelon, L. and Muchiri, P., 2010. Maintenance optimization models and criteria. International Journal of System Assurance Engineering and Management, 1(3), pp.189-200.

Velmurugan, R.S. and Dhingra, T., 2015. Maintenance strategy selection and its impact in maintenance function: a conceptual framework. International Journal of Operations & Production Management, 35(12), pp.1622-1661.

Wang, W.J., Chang, Y.S., Lo, W.T. and Lee, Y.K., 2013. Adaptive scheduling for parallel tasks with QoS satisfaction for hybrid cloud environments. The Journal of Supercomputing, 66(2), pp.783-811.

Yu, A.J. and Seif, J., 2016. Minimizing tardiness and maintenance costs in flow shop scheduling by a lower- bound-based GA. Computers & Industrial Engineering, 97, pp.26-40.

Zhang, Y., Andrews, J., Reed, S. and Karlberg, M., 2017. Maintenance processes modelling and optimization. Reliability Engineering & System Safety, 168, pp.150-160.

Zhu, H., Liu, F., Shao, X., Liu, Q. and Deng, Y., 2011. A cost-based selective maintenance decision-making method for machining line. Quality and Reliability Engineering International, 27(2), pp.191-201.

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