HVAC Equipment's Spare Parts Optimization in Saudi Arabia

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Abstract

The paper is to optimize the cost and storing spaces of the inventory of the Firms' HVAC spare parts without affecting the minimum required quantity of spare parts. Three models were introduced and simulated to calculate the required spare parts and their cost. The results of each model were evaluated and compared against the base case and the other proposed model. The best model was found that warehouse will be grouped into three groups based on their geographical locations. All the spare parts required for all locations in each group will be consolidated and allowed the lateral movement between group's locations. The cost can be reduced by 28 percent, and the number of parts can be less by 25 percent.

Keywords
HVAC, HVAC System, Air-Condition, Spare, Parts, Optimization, Saving, Chiller, Quantity, Warehouse, Store, Maintenance, Critical, Equipment, Saudi, Arabia.

1. Introduction
In sunny and harsh weather HVAC equipment became one of the critical equipment in any building or facilities. HVAC systems is Saudi Arabia are running around the clock most of the year. The impact of equipment's availability which is a function of reliability and maintainability depends on the criticality of the facility (Gulati 2013). For example, a failure in the HVAC System for a hospital is not like a failure that could happen at recreation facility. Moreover, HVAC system downtime also plays major role in the failure impacts. These days, maintenance has become essential for the operation of complex production systems. Moreover, lack of maintenance due to missing spare parts could result in breakdown that has major negative impacts on the operation (Espíndola et al. 2012)

The majority of the HVAC Systems' spare parts are imported from outside the kingdom of Saudi Arabia where the delivery time and cost play the major role in the spart parts availability. Spare parts inventory is commonly used by the large firms to secure their need of their HVAC Systems. The case that was address in this paper is a large maintenance services firm that has many contracted facilities scattered all over the kingdom of Saudi Arabia. The firm's contracted facilities have different level of the criticality of their HVAC Systems. The HVAC System in hot country like Saudi Arabia is very essential; however, the criticality in these facilities is measured based on the impact of the safety and the facilities' production and operations.

Moreover, the firm is currently facing space issue in its warehouses. Every department at the firm has its own stores and inventory strategies with no lateral movement between the departments' stores. Also, these warehouses are geographically scattered based on the operation's locations. Figure 1 and 2 demonstrate the organization's chart and warehouses' locations distribution. Also, spare parts value plays major roles where the inventory value has a limitation that covers different operation and maintenance requirement rather than HVAC system.

For the simplicity, the three types of air-cooled chillers were selected for this paper. It is commonly used across the firm's facilities. Also, it is a major equipment in the HVAC system, and its failure leads to HVAC system failure. A total of 35 air-cooled chillers of type A, 21 air-cooled chillers of type B and 14 air-cooled chillers of type C that have similarity in most of the required spare parts. As a best practice, there is a minimum quantity of spare parts for each four air-cooled chillers or less that shall be stored for breakdown maintenance.

1.1 Objectives

The objective of this project is to optimize the cost and storing spaces of the inventory of the Firms' HVAC spare parts without affecting the minimum required quantity of spare parts as it specify in the equipment critical spare parts best practices.

2. Literature Review

Inventory optimization is one of the active subjects in supply chain management. Many articles were found addressing the spare part availability issue through out other areas such as the organization maintenance strategy, the spare parts' supplier selection and the process maturity. The literature has devoted limited attention to inventory management and forecasting methods to ensure the availability of spare parts and to optimize the inventory (Achetoui et al. 2019). Moreover, literature has not covered the HVAC spare parts sector in Saudi Arabia.

Several quantitative and qualitative classification methods were discussed in the literatures that are using a set of criteria for effective inventory management such as criticality, volume of demand, cost of spare parts, time of replenishment, availability of suppliers and unpredictability of demand. Moreover, optimizing the spare parts shall not affect the operation downtimes and maintenance activities. Minimizing downtimes of the maintained systems shall not rely on high inventory volumes. Safety stocks of spare parts can only be achieved by precisely forecasting system breakdowns in combination in addition to an efficient coordination of the spare parts supply chain to make the required parts available at the right location and time. Due to the unexpected pattern of breakdowns, the application of classical forecasting methods cannot provide satisfactory level of spare parts' demand forecasts (Hellingrath and Cordes 2014).

One of the common practices to reduce the effects of the downtime of the critical equipment is that design a backup and standby equipment (Gulati 2013). By this, incase of breakdown, spare parts can be ordered when it is required, and there will be no issue waiting for the parts. However, this will increase the capital investments of the building or plant. Also, the standby equipment requires additional space which in some cases is not available or it can be utilizes for more profitable equipment's.

Moreover, high stock level is another way to reduce downtime of the critical equipment and shortage costs (Hasni et al. 2019). However, 'how to control the stock efficiently and ensuring the availability of spares?' is the important question that must be addressed in the inventory management according to Gill, Khullar, and Narinder (2016). Maintaining good spare parts inventory is important to achieve excellence in maintenance performance. cost savings opportunities in the manufacturing, services and defense sectors can be achieved by engaging in a more efficient management of spare parts inventories (Roda et al. 2014). To accomplish these targets, more attention is required by the literature to inventory management and forecasting methods to ensure the availability of spare parts and to optimize the inventory. Moreover, it is not an easy task to forecast the required spare parts for the breakdown maintenance activities.

3. Methods

Simulation models were used to evaluate the different configurations of the system to be optimized. The current system was deeply reviewed, and several seniors were suggested for the optimization simulation model. The cost of the critical spare parts was calculated for each scenario. Moreover, to optimize the inventory required space, the number of required spare parts were minimized for each scenario.
The simulation model was developed by Microsoft Excel. Bar charts were developed to compare the result of each scenario for both the cost and space.

4. Data Collection

In order to achieve the objective of this project all the required data was collected. Critical Spare Parts list (table 1) were collected from the firm's best practices for the three selected HVAC equipment for this project. 59 items are the consolidated critical spare parts for the three selected type of chillers.

Table 1 Required Critical Spare Parts

Description	Req. Q for every 4 Chillers or less			Unit Price
	Type A	Type B	Type C	
Compressor (CSH7571-90Y)	1	1	0	$11,806.67
Compressor (CSH7571-85Y)	0	0	1	$13,635.17
Expansion Valve	4	4	4	$6,470.67
Acces valve (3434)	15	0	0	$23.00
Acces valve (34664)	0	15	15	$23.00
Ball Valve	3	0	3	$85.87
Solenoid Valve	3	3	3	$372.91
Cordri RC4864 Core Drier	96	0	0	$22.69
Filter Drier Replaceable Core 1-1/8	3	3	3	$217.73
3P Contactor 9A 220V Coil 50/60HZ	8	8	8	$28.75
3P Contactor 95A 220V Coil 50/60HZ	5	5	5	$141.07
3P Thermal OLR MNX R4 45.0-75.0A	5	5	5	$56.43
Relay DPDT-2 Form C 240V-240V 50/60HZ	4	4	4	$16.56
Relay Time Delay 24V-240	4	4	4	$47.84
Earth fault Relay with Delay Time	3	3	3	$622.23
Toggle SwitchSPDT 3 Amps	2	2	2	$4.91
Switch Disconnector 1000A	2	2	2	$1,932.00
Control Hi-Pressure 350 PsiG-R134a	3	3	3	$9.81
Thermal manetic crbkr 3P 9ln 80-100A 500V	5	5	5	$78.20
Miniature Circuit breaker 3P 10A 480VAC	4	4	4	$118.07
Fusdel Dual Element 8 AMP 250V	24	24	24	$3.99
Fusdel Dual Element 15 AMP 500V	24	24	24	$10.43
Fushdr 1P_30A_600V_13/32"	3	3	3	$4.91
Transformer 208/230/460 VAC-24 VAC 100A	0	1	1	$34.96
Transformer 50VA 208/240/ to 12	2	0	0	$52.13
Voltage Monitor	1	1	1	$150.27
Sight Glass 3/8 SWT	3	3	3	$24.53
Fan Assembly TB	0	8	0	$950.67
Fan Assembly TC	0	0	8	$950.67
Fan Assembly TA	8	0	0	$950.67
Micro controller Micro Smart	1	1	1	$1,320.20
User Interface Card-CH	1	0	0	$315.25
PTC Temp. sensor for LWT&RWT CH (PJE)	5	5	5	$47.23
Relative PR Transducer (0-40 Bar)for DP	0	2	0	$154.87

Relative PR Transducer (05-10 Bar)for SP	0	2	0	$154.87
Micro Controller EEV Board,24VAC 50/60HZ	0	1	1	$608.73
Toroid	1	1	1	$90.47
CABLE; ASSEMBLY MULTI-CONNECTOR	1	1	1	$1,880.48
CABLE; 4-WIRE RIBBON, FLAT CABLE, 100 FT	1	1	1	$598.61
CABLE; COLUMN TO COLUMN (EACH = 8 ")	1	1	1	$26.98
CABLE; COLUMN TO STARTER MODULE	1	1	1	$19.62
CABLE; 4 WIRE RIBBON, FLAT CABLE, 500 FT.	1	1	1	$2,881.44
SENSOR TEMPERATURE;	6	6	6	$809.60
TRANSDUCER PRESSURE	6	6	6	$1,449.92
KIT; HARNESS GLOBAL; KIT12559	0	0	10	$371.06
BUTTER FLY VALVE; TRANE P/N: VAL07081	0	3	3	$1,565.84
VALVE; EXPANSION TRANE P/N: VAL08754	0	1	0	$1,395.33
VALVE; EXPANSION TRANE P/N: VAL08751	0	1	0	$1,472.00
TANK; BRAZED PLATE HEAT EXCHANGER	0	3	0	$2,346.00
VALVE .88ODSX.62ODS TRV TRANE P/N: VAL07089	0	3	0	$1,182.20
KIT LIQUID LINE; TRANE P/N: KIT07614	0	3	0	$614.56
VALVE; BALL; TRANE P/N: VAL07337	0	3	0	$696.44
BRACKET BRAZED COOLER; TRANE P/N: BRK02913	0	3	0	$138.00
SCREW; ROL THD; TRANE P/N: SCR01632	0	6	0	$13.80
ADAPTOR; TRANE P/N: ADP01048	0	2	0	$46.00
SLEEVE; REDUCER; TRANE P/N: SLV00190	0	2	0	$310.96
COPPER PIPE SET	3	3	3	$6,900.00
OIL; TRANE P/N: OIL00048	0	10	0	$1,487.33
OIL FILTER; TRANE P/N: FLR03434	0	6	0	$515.20

Moreover, the distance between equipment's locations were estimated by google earth. Table 2 shows the distances in kilometers.

Table 2 Distance Between Locations (KM)

Location	L1	L2	L3	L4	L5	L6	L7	L8
L1		250	450	200	250	800	1250	1100
L2	250		300	300	325	850	1200	1100
L3	450	300		500	650	450	700	600
L4	200	300	500		200	500	1300	1200
L5	250	325	650	200		600	1400	1300
L6	800	850	450	500	600		700	1000
L7	1250	1200	700	1300	1400	700		400
L8	1100	1100	600	1200	1300	1000	400	

5. Supply Chain Network Modeling

Three models additional to the current situation were evaluated in terms of cost and number of required spare parts to be stored. Current situation was used as a base for the simulation.

Base Model:

This is model presents the current situation in the firm which is every operation location has its own warehouse to store the required spare parts. There was no lateral movement between the warehouse to exchange the spare parts. Moreover, each manages its own required parts. Figure 1 shows the scattered warehouses' location on the map.

Model 1:

This model is one of the proposed models to optimize the spare parts cost and number at the firm. In this model all the spare parts required for all locations will be consolidated and the lateral movement will be allowed between all locations. Figure 2 shows the locations of the warehouses and the allowable lateral moves between them. Moreover, all locations will be linked with each other in term of identifying and calculating the required critical spare parts.

Model 2:

This model is the second proposed model to optimize the spare parts cost and number at the firm. In this model, warehouse will be grouped on three groups based on their geographical locations. All the spare parts required for all locations in each group will be consolidated and the lateral movement will be allowed between group's locations. Figure 3 shows the proposed groups' locations of the warehouses and the allowable lateral moves between them. Moreover, group's locations will be linked with each other in term of identifying and calculating the required critical spare parts.

Model 3:

This model is the third proposed model in this project to optimize the spare parts cost and number at the firm. In this model, warehouse will be grouped on three groups based on their administration departments. All the spare parts required for all locations in each group will be consolidated and the lateral movement will be allowed between group's locations. Figure 4 shows the proposed groups of the warehouses and the allowable lateral moves between them. Likewise, group's locations will be linked with each other in term of identifying and calculating the required critical spare parts.

Figure 1 Warehouses' locations on the map

Figure 2 Locations of the warehouses and the allowable lateral moves for model 1

Figure 3 Locations of the warehouses and the allowable lateral moves for model 2

Figure 4 locations of the warehouses and the allowable lateral moves for model 3

6. Supply Chain Improvements

The three proposed models aim to improve the supply chain in order to meet the objective which is to optimize the required critical spare parts to reduce cost and required space. Each model of these has its pros and cons. Model 1 will reduce the number of required spare parts because it is consolidating all the equipment because the used maintenance best practice identified the required quantity of spare parts for every four 4 chillers or less. For example, the best practice is to have one compressor as a spare for every four 4 chillers or less. Location 1 and 3 have two chillers each, so it is required to store at least one compressor at each location. But it is only required one compressor if both locations were consolidated in term of identifying and calculating the required critical spare parts. However, model 1 requires the longest average traveling distance between the consolidated locations compare with other proposed models. Then, Model 2 and 3 were proposed to reduce the average traveling distance between the consolidated locations. Thus, out of this simulation the best model would be the model that will required less spare parts which will lead to less cost and storage space.

7. Results and Discussion

The three models were simulated to calculate the required spare parts and their cost. The results of each model were evaluated and compared against the base case and with each other's. the best model was selected based on three criteria which are cost, number of spare parts and traveling distance for lateral movements between consolidated locations.

The best model was found that model 2 gives the lowest cost, less parts to be store and the shortest travel distance between locations. Model 2 will reduce the cost by 28 percent, and the number of parts will be less by 25 percent. The average traveling distance between locations for the lateral moves is 371 kilometers.

7.1 Numerical Results

Table 3 summarized the results of the simulations foreach proposed model. Also, it shows the optimization percentage for each model comparing with the base case.

Table 3 Results Summary

	Cost	Parts Total Quantity	Average Distance Between Locations (KM)	Optimization %	
				Cost	Space
Base Case	$ 3,176,764.85	6215	0		
Model 1	$ 2,176,270.42	4361	710	31.5%	29.83%
Model 2	$ 2,276,541.51	4624	371	28.3%	25.60%
Model 3	$ 2,276,541.51	4624	617	28.3%	25.60%

7.2 Graphical Results

Figure 5 presents the cost of required spare parts for the three proposed models in addition to the existing practice cost. Model 1 is the lowest cost among all results which is less by 31.5% compare to the base case. Then, model 2 and 3 are less by 28.3%

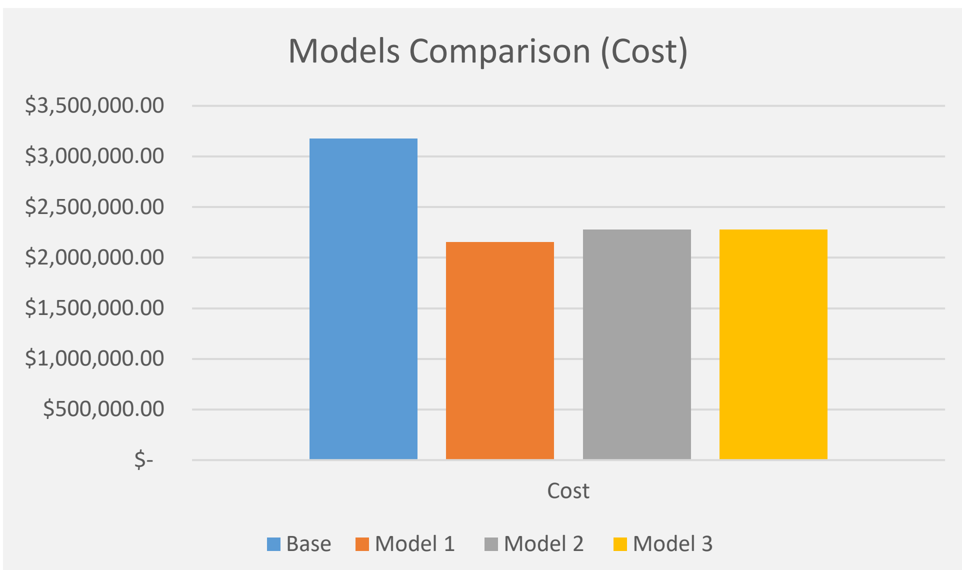

Figure 5 Models Comparison of Cost

Figure 6 presents the comparison of the model results in the quantity of required spare parts.

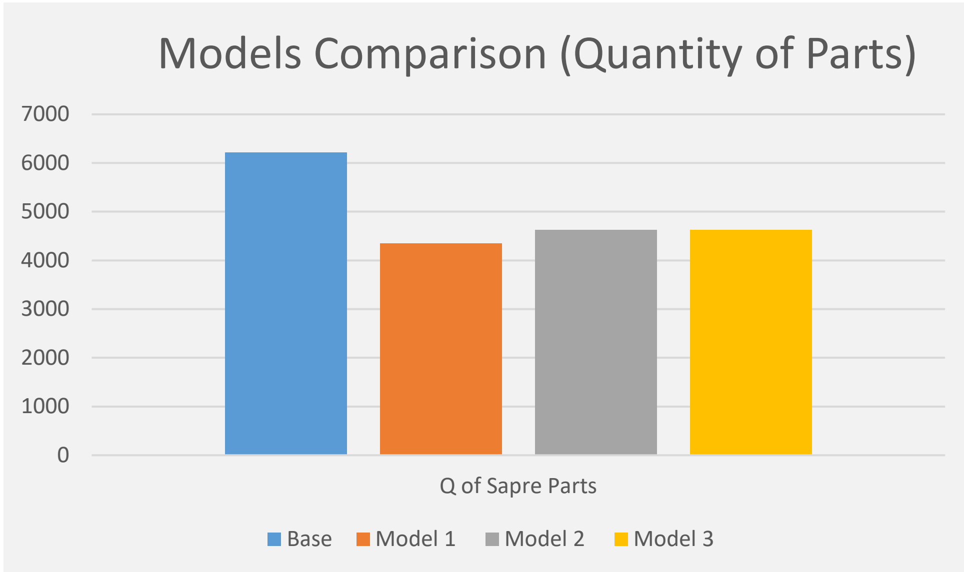

Figure 6 Models Comparison of Quantity

Figure 7 shows the average of the required traveling distances for the lateral movements in each model. The average traveling distance is zero for the base case because currently there is no lateral moves. Model 2 has the shortest of the average traveling distance between locations which is 371 kilometers.

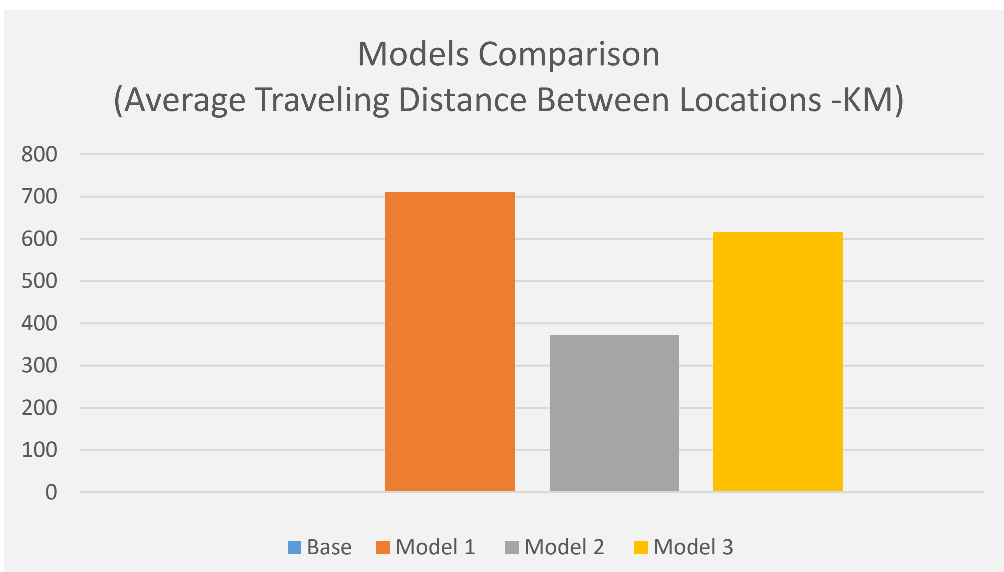

Figure 7 Models Comparison of Traveling Distance Between Locations

6. Conclusion

Maintaining good spare parts inventory is important to achieve excellence in maintenance performance. To accomplish this target more attention is required by the literature to inventory management and forecasting methods to ensure the availability of spare parts and to optimize the inventory. Moreover, it is not an easy task to forecast the required spare parts for the breakdown maintenance activities.

The objective of this project is to optimize the cost and storing spaces of the inventory of the Firms' HVAC spare parts without affecting the minimum required quantity of spare parts as it specify in the equipment critical spare parts best practices. Three models were introduced and simulated to calculate the required spare parts and their cost. The results of each model were evaluated and compared against the base case and the other proposed model. The best model was found that model 2 gives the lowest cost, less parts to be store and the shortest travel distance between locations. In this model, warehouse will be grouped on three groups based on their geographical locations. All the spare parts required for all locations in each group will be consolidated and the lateral movement will be allowed between group's locations. Model 2 will reduce the cost by 28 percent, and the number of parts will be less by 25 percent. The average traveling distance between locations for the lateral moves is 371 kilometers. Moreover, the method and the proposed solution that were used in this project can be applied for all type of equipment's spare parts optimization.

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Biography

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