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Effective Forecasting and VMI for Critical Maintenance Non-Repairable Parts in Residential Facilities in Riyadh, KSA

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Abstract

Vendor Managed Inventory (VMI) has been one of the most valuable strategies that provides a number of benefits for both suppliers and customers. There was an impact on the proposed improvement practices listed, including VMI that enhanced and smoothened spare parts supply chain management. For suppliers, it can help to improve customer satisfaction by ensuring that they always have the products they need in stock. It can also help to reduce inventory costs by eliminating the need for the supplier to carry excess inventory. For customers, VMI can help to free up resources that can be focused on other areas of the business, such as sales and marketing. It can also help to improve inventory visibility and accuracy, and reduce the risk of stockouts. In this study, the services provided at residential complexes of the case study in Riyadh, Saudi Arabia have been listed, and then have found the most critical services to the tenants by conducting a scoring questionnaire. These services have been analyzed and listed the most common issues and have went through their supply chain process to rate the supply chain interruption risk. The highest rated risk service has been picked up as an example to apply the forecasting methodology. The historical data has been used for the elevators main board to draw the curve of occurrences probability. The curve equation has been found in order to use it as a forecasting tool. The finding shows the upcoming year expected demand using the mathematical calculations.

Keywords
Supply chain, Vendor managed inventory (VMI), Maintenance, and Facility management.

1. Introduction
Effective supply chain management plays an important role to ensure the continuity of the services provided in residential complexes, and therefore stopping them or operating inappropriately will directly affect the satisfaction of the residents and affect the reputation and thus the commercial value and profits. Accurate demand forecasting can help facility managers to reduce costs by avoiding the need to order and stock unnecessary parts, improve efficiency by ensuring that the right parts are available when they need them, reduce downtime and disruptions to services and improve resident satisfaction. (Karthika, 2020).

This study is significant because it will provide facility managers with a better understanding of how to forecast demand for spare parts for critical services in residential facilities (Nazali, 2009) and how to implement VMI. VMI is a collaborative approach to supply chain management that can lead to improved supplier-customer relationships (Marquès, 2010). This can lead to better communication and cooperation, which can benefit both parties. Overall, the data in this study has been collected from 5 residential complexes by performing visits to the assigned property managers and through questionnaires spread to 40 tenants.

1.1 Objectives

The objective of this study is to provide a supply risk assessment analysis to the most critical services by listing all services provided at residential complexes in Riyadh Saudi Arabia and to find out which of these services are the most critical and important to the tenants. This will provide forecast mathematical equation on the highest risk rated service and the suggested ordered quantities and stock levels. This study will provide a sound analysis of the vendor managed inventory to minimize the supply risk.

2. Literature Review

A supply chain is a system of individuals, organizations, resources, activities, and technology interacted to deliver services or products. It is a long chain of processes starting from delivery of raw materials to manufacturing to their eventual delivery to the end user, supply chains are vital to the world economy, playing a vital role in delivering the goods and services that everybody depend on every day. In today's interconnected world, supply chains are often complex and globalized, involving many suppliers and customers located in different countries. (Nazali et al. 2009).

Effective supply chain management is critical for businesses of all sizes. By optimizing their supply chains, companies can reduce costs, improve efficiency, and increase customer satisfaction. Supply chain vertical integration is a very important practice in which the organization will do and perform forward or backward stages in the supply chain, this kind of integration needs larger budget and expertise but it has another advantage which is reducing operation discontinuity risk (Babaveisi 2023).

A non-repairable part in residential facilities are the components that cannot be fixed or restored to its original condition after it breaks down. It must be replaced with a new part (Hassan, 2012). Non-repairable parts are often used in critical systems, where failure could have serious consequences. They are also used in products where the cost of repair is greater than the cost of replacement. Service scoring is a structured perform evaluation and to manage performance of facilities management services. It includes identifying a set of key performance indicators (KPIs) relevant to the facility and the specific services being evaluated, and then end up with a score for each service. (Rasolofo-Distler and Distler 2018).

Facility managers must prepare strategic plans to manage supply chains related to services provided in residential facilities. An effective supply chain planning plays an important role in the smooth operation of these facilities and the services provided therein (Mangano and De Marco 2014).

Figure 1 shows spare repairable and non-reparable spare parts movements in a residential facility inventory.

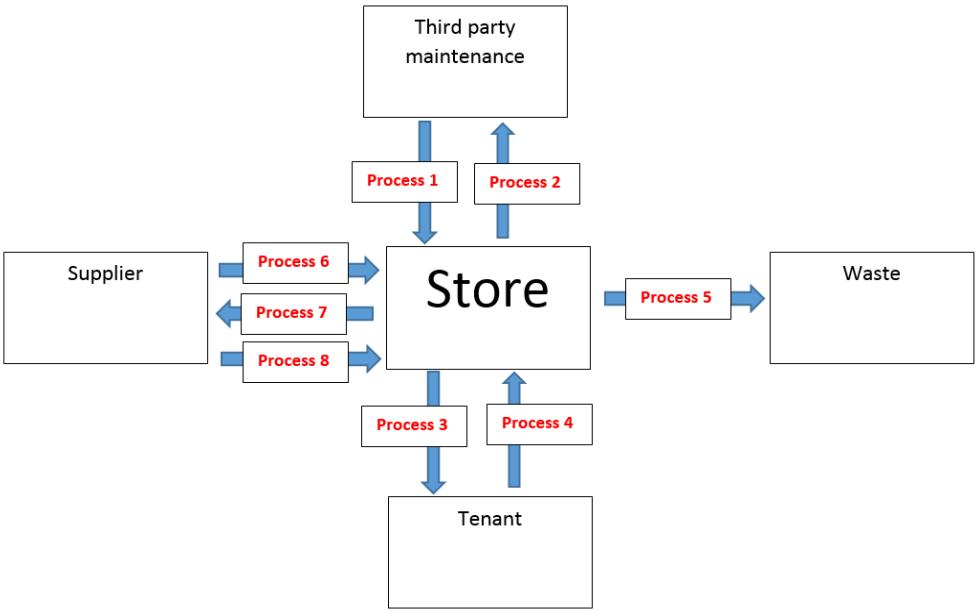

Figure 1. Inventory processes diagram

Process 1: Receiving the appliance from the third party after fixing.
Process 2: Sending the appliance to the third party to fix.
Process 3: Return the appliance to the tenant.
Process 4: Receiving the appliance from the tenant.
Process 5: Sending to the waste after evaluation.
Process 6: Receiving the appliance from the supplier after fixing.
Process 7: Sending the appliance to supplier to fix (under warranty).
Process 8: Ordering a new appliance.

Recording data is essential for effective facility management. By recording data, facility managers can make informed decisions, comply with regulations, improve efficiency, reduce costs, and improve sustainability (Jang and Collinge 2020). These data significantly help top management to create statistical graphs to efficiently manage their facility and to take strategic decisions, this decision includes suppliers' selection, root cause analysis and forecasting, Forecasting is essential for facility maintenance management (Abdeen 2022) because it helps to:

- Predict future maintenance needs and costs. This allows facility managers to budget and plan for maintenance activities, and to avoid costly surprises (Van, 2020).
- Identify potential problems and take preventive action. By forecasting maintenance needs, facility managers can identify potential problems before they cause major disruptions or failures. This can help to reduce costs and extend the life of equipment and facilities.
- Improve the efficiency and effectiveness of maintenance operations. By having a good understanding of future maintenance needs, facility managers can schedule maintenance activities in a way that minimizes downtime and disruption. They can also allocate resources more effectively and ensure that the right people and parts are available when needed.
- Improve communication with stakeholders. By sharing maintenance forecasts with stakeholders, facility managers can help to set expectations and build trust. This can also help to secure funding for maintenance activities and ensure that they are prioritized appropriately.
- Contribute to the overall sustainability of the organization. By forecasting and planning for maintenance activities, facility managers can help to reduce waste, conserve resources, and extend the life of assets. This can help to reduce the organization's environmental impact and improve its sustainability performance.

Vendor Managed Inventory (VMI) is a collaborative approach to supply chain management in which the supplier takes responsibility for managing the inventory levels of their customer. This can be done through a variety of methods, such as using electronic data interchange (EDI) to track inventory levels and automatically place orders when necessary, or by having the supplier physically manage the inventory at the customer's site that is represented in Figure 2 (supplyon, 2023).

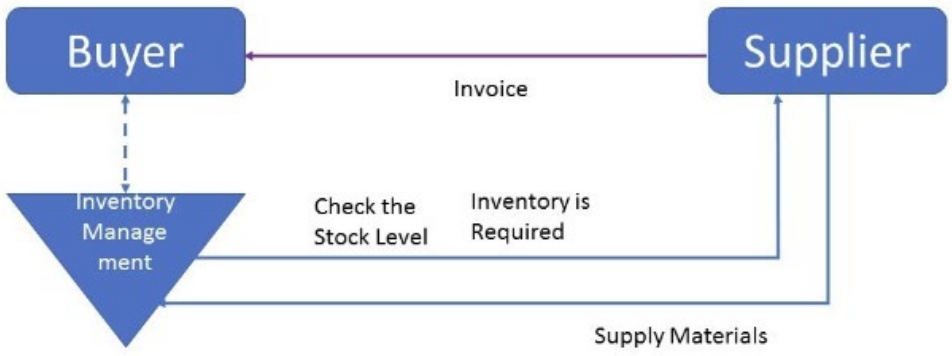

Figure 2. VMI workflow

3. Methods

A list of collected services provided in some of residential complexes in Riyadh Saudi Arabia, is surveyed with a questionnaire conducted including a number of forty residents to score these services. After that, all questionnaire scoring was added to find out the most critical services to the tenants and then arranged the services from most important to the least important by using pareto chart. Then, personal interviews were conducted with professionals

working in the field of residential facility maintenance to collect information about the difficulties they face in the maintenance process, including supply, warehousing, and installation. After that, a qualitative tool was used to find out the services and issues with a high risk rated supply chain or maintenance process, finally, suggestions to how control these risks and how to improve the supply chain process were listed.

4. Data Collection

The data used for this study was collected from five different closed community complexes in Riyadh, Saudi Arabia, these complexes provided several services such as: maintenance, security and common area cleaning, also these complexes contain facilities such as: swimming pools, gym, kids' playground and parking lots, table 1 shows some information about these complexes.

Table. 1 Complexes information

Residential Complex	Building Age	Number of Units
Complex 1	6	110
Complex 2	8	152
Complex 3	7	105
Complex 4	6	85
Complex 5	7	45

The total number of respondents in the survey were 40 respondents, 8 respondents from each complex, the marital status of residences affects their needs and services scoring, Figure 3 shows the marital status for the sample.

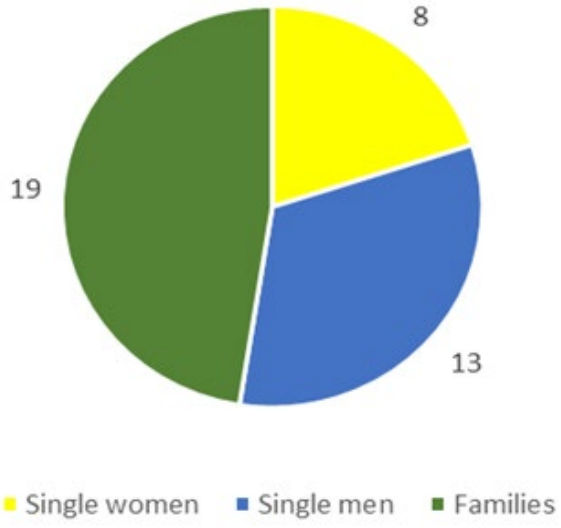

Figure. 3 Respondents marital status

5. Results and Discussion

5.1 Numerical Results

First, the beginning was by listing all the services provided in the closed residential complexes, as these services include common facilities, maintenance services, furniture and units' appliances. Table 2 below shows the respondents services scoring in which it can then be sorted from the highest to lowest

Table. 2 Respondents services scoring

	Rating from 1 to 10 (10 is highest)																
	Lightings	Water supply	Elect power	A/C	Fredg	Oven	Laundry	Heater	Dish washer	Garage	Agriculture	Elevators	Network Signal	Sanitory	Furniture	Floors	Paints
Tenant 1	4	5	5	5	3	2	1	3	5	4	2	5	3	2	1	1	1
Tenant 2	5	4	5	5	5	2	2	3	2	4	2	4	5	4	4	3	4
Tenant 3	3	4	5	4	5	3	1	3	5	4	1	4	5	2	1	2	3
Tenant 4	4	5	5	4	3	3	3	2	4	3	2	4	4	3	1	4	1
Tenant 5	2	5	5	5	4	3	4	5	1	3	1	4	5	3	4	2	3
Tenant 6	2	4	4	4	4	1	4	4	2	5	2	5	4	2	2	1	3
Tenant 7	4	4	5	4	5	3	1	4	2	4	3	5	4	1	4	3	2
Tenant 8	3	5	4	4	4	4	2	3	1	4	1	4	5	4	4	1	3
Tenant 9	4	4	5	4	5	1	4	4	1	3	2	4	5	4	1	2	1
Tenant 10	2	4	5	5	4	4	4	4	2	5	3	4	5	4	1	1	3
Tenant 11	3	4	5	4	5	2	4	3	1	4	1	4	5	1	1	4	2
Tenant 12	4	4	4	4	4	5	3	5	1	4	2	5	4	1	4	1	3
Tenant 13	4	5	4	4	4	4	4	2	3	4	2	5	4	4	2	2	2
Tenant 14	3	5	5	4	3	3	3	4	5	2	3	4	5	2	4	2	2
Tenant 15	3	4	5	5	4	3	4	5	3	5	2	4	4	4	3	4	3
Tenant 16	1	5	5	4	4	3	3	5	3	5	1	4	5	3	1	4	2
Tenant 17	4	5	5	5	4	3	3	5	1	5	1	4	4	4	4	4	4
Tenant 18	4	5	4	5	5	1	4	5	5	5	3	5	5	1	2	3	1
Tenant 19	3	4	4	5	3	1	2	5	1	2	2	5	5	2	2	3	4
Tenant 20	4	5	5	5	4	3	5	3	3	1	1	4	5	3	2	2	2
Tenant 21	4	4	5	5	5	3	1	4	4	3	3	5	4	1	3	1	4
Tenant 22	4	5	5	5	5	2	4	5	5	4	1	4	5	2	3	1	1
Tenant 23	3	4	5	4	5	2	2	2	3	3	2	4	4	1	2	2	2
Tenant 24	3	4	5	5	4	1	1	3	4	3	3	5	4	2	1	1	1
Tenant 25	4	5	5	5	5	1	4	5	3	5	2	5	4	1	2	3	2
Tenant 26	3	5	5	5	4	3	2	5	3	4	1	4	5	3	4	4	1
Tenant 27	4	5	5	4	4	4	3	3	5	5	2	5	5	3	1	2	2
Tenant 28	4	4	4	4	5	1	2	4	3	3	1	5	4	1	3	1	1
Tenant 29	4	5	4	4	4	4	1	4	2	3	1	4	5	4	2	4	3
Tenant 30	2	4	4	4	5	4	2	3	2	3	2	5	4	4	1	4	3
Tenant 31	4	4	5	4	5	2	4	4	3	4	3	4	4	3	4	2	1
Tenant 32	2	5	4	4	4	4	5	4	2	5	2	5	5	1	4	3	2
Tenant 33	2	5	5	5	5	1	3	4	1	4	1	3	4	2	4	4	4
Tenant 34	2	5	4	4	4	3	1	5	5	5	1	5	5	4	2	1	2
Tenant 35	2	5	4	5	3	4	2	5	4	4	3	4	5	4	3	2	4
Tenant 36	3	5	5	5	4	1	2	4	3	4	3	5	4	2	4	3	1
Tenant 37	2	4	5	4	4	3	2	4	3	2	4	4	5	1	4	4	3
Tenant 38	3	5	4	4	3	2	1	2	3	3	2	5	4	1	4	1	3
Tenant 39	4	5	5	5	3	1	1	5	2	2	3	4	5	3	3	3	1
Tenant 40	3	4	5	4	5	3	4	4	2	5	3	4	4	3	1	3	1
	128	182	187	178	168	103	108	156	113	150	80	176	180	100	103	98	91

Pareto chart has been used to sort services from the highest to lowest, Figure 4, the top highest five scored critical services to the tenants are: electrical power, water supply, network signal, A/C and Elevators respectively.

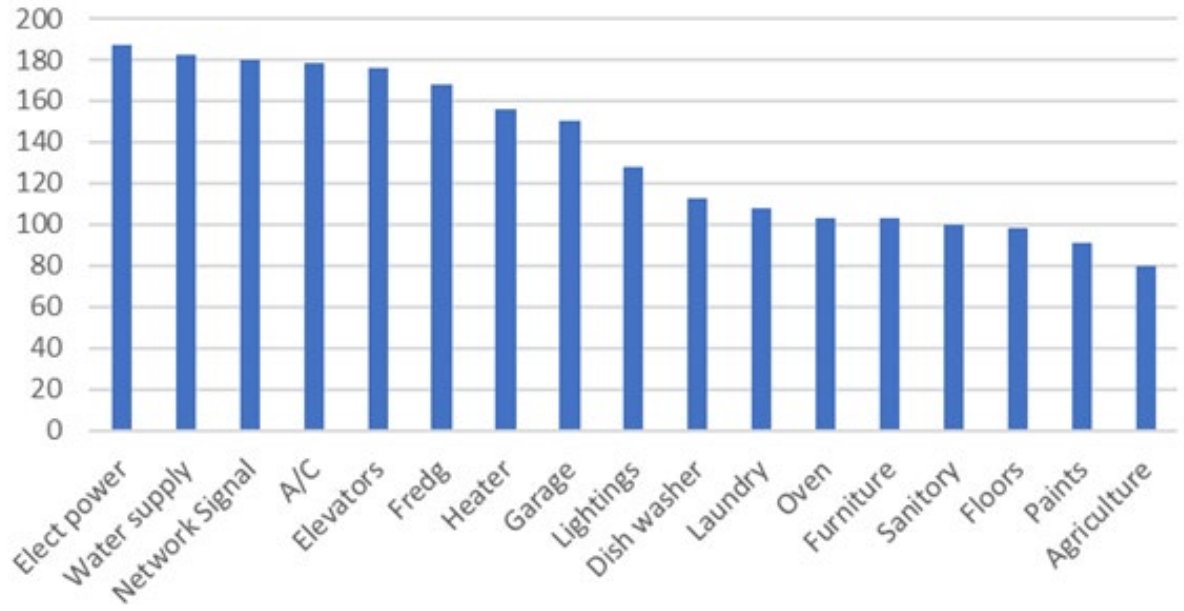

Figure 4. Sorting services scoring from highest to lowest

Table 3 below lists the highest five critical services based on previous pareto chart and the supply risk was then analyzed and the total risk rating was obtained: Low, medium, high and very high respectively.

Table. 3 Supply Risk rating

Factor	Common Issues	Back up system	Common Needed spare parts	Parts with supply issues	Estimated Lead Time	Time for Insallation	Technical expertise	Risk rating
Elect power	Power off Current not stable	Emergency lights	Wires Relys Breakers	No	Same day	Same day	Low	**Low**
Water supply	No supply Weak Pressure Pressure flactuating Leakages	Manual mechanical sensors Roof tanks work by gravity Bypass piping	Main pump Booster Pump Pressurized tank VFD system Valves	VFD system (Variable frequency drive)	2 days	4 days	High	**High**
Network Signal	Weak signal	No	Network booster	No	Same day	2 days	Low	**Medium**
A/C	Cooling issues Leackages Noise	No	R-134a Welding machine Compressor Capacitor Motor fan bearings	Compressor	5 days	Same day	High	**High**
Elevators	Out of service People stuck Cart jerk Noise	Electric Batteries for emerge	Main electronic board Electronic chips Pullys	Main electronic board Electronic chips	45 days	1 day	High	**Very High**

As shown in table 3, the elevators have been rated as the highest service with supply risk, so that the decision was to take it as the case study is how to analyze, forecast and control (supply and demand) to mitigate the risk.

Replacement rate is an important step in which the predicted demand is covered in advance to avoid critical part out of stock or long time out of service (Archer, 1987). Table 4 below shows how to calculate accumulative replacement rate for elevator main board spare part, based on historical data for the 35 elevators for 7 years, that for the first three years there was no replacement of spare parts, and after that, replacement incidents began to increase, following an exponential function (Brocks, 2016).

Table. 4 Accumulative replacement rates

			Number of elevators have changed their main board					
Residential Complex	**Building age**	**Total number of elevators**	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Complex 1	6	12	0	0	0	0	2	3
Complex 2	8	10	0	0	0	0	1	2
Complex 3	7	8	0	0	0	0	0	1
Complex 4	6	3	0	0	0	0	1	1
Complex 5	7	2	0	0	0	1	0	0
		35	**0**	**0**	**0**	**1**	**5**	**12**
		Accumulative Replacement Rate	**0%**	**0%**	**0%**	**3%**	**14%**	**34%**

5.2 Graphical Results

Using the data in table 4. “the accumulative replacement rates” the graph of replacement probability was drawn, Figure 5 shows the historical demand “replacement occurrences” during the past 7 years, a curve was created using MS excel to find the curve equation, this equation is used as the forecasting equation in which it will predict the number of replacements during the upcoming years. Another advantage of this curve is to compare this part with another alternative spare parts by calculating part cost vs lifetime. (Chawla, 2019)

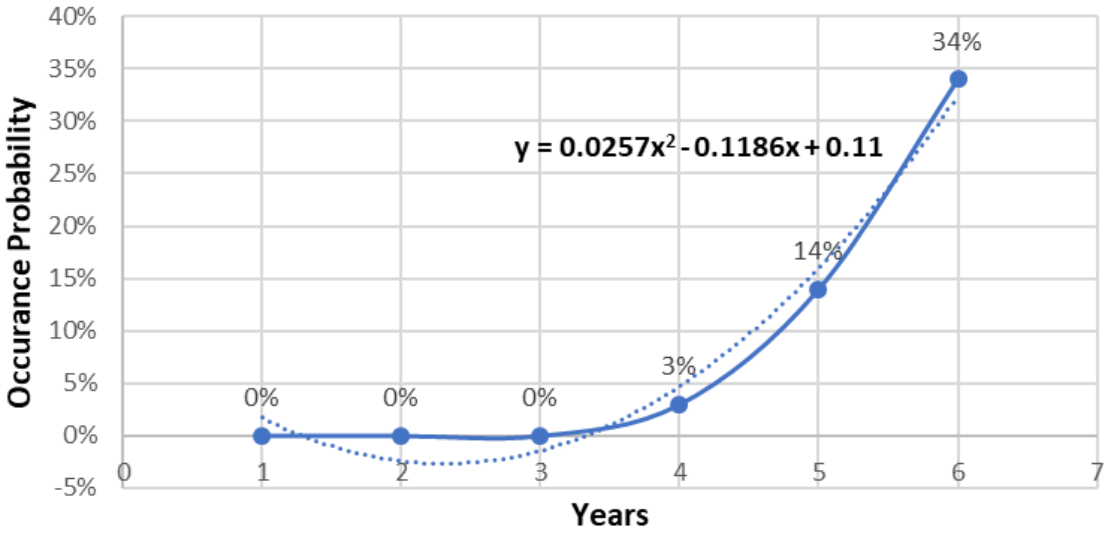

Figure 5. Elevator main board replacement probability

The Prediction equation of the demand forecasting during year 8 is as follows:

$$y = 0.0257x^2 - 0.1186x + 0.11$$
$$y = 59\% \text{ of } 35 \text{ boards}$$

So, approximately accumulative of 12 boards of the 35 boards will need replacement at the end of year 7. If 12 boards were already replaced and the total prediction at the end of year 8 is 21, forecasted demand for year 8 will be as follow:
Forecasted demand for year (n) = Total prediction at the end of year (n) - total replacement at the end of year (n-1)
So, forecasted demand for year (8) = total prediction at the end of year (8) - total replacement at the end of year (7)
Hence, forecasted demand for year (8) = 21 – 12 = 9
Estimated of 9 boards to be ordered during year 8, see table 5.

Table 5. Year 8 order quantity forecast

		Trend	Accumulative Quantity	Calculated Yearly Quantity	Actual Quantity
Historical Data	**Year 1**	0%	0	0	0
	Year 2	0%	0	0	0
	Year 3	0%	0	0	0
	Year 4	0%	0	0	0
	Year 5	3%	1.05	1.05	1
	Year 6	14%	4.9	3.85	4
	Year 7	34%	11.9	7	7
Forecast	**Year 8**	59%	20.51	8.61	9

The order quantity and stock level graph, is a graphical representation of the total demand associated with period of time. It is used to determine the optimal order quantity that minimizes total costs (Mohd, 2013), and to ensure the availability of needed items. The resulted forecasted order quantity for year 8 for the elevators main board part is shown in Figure 6.

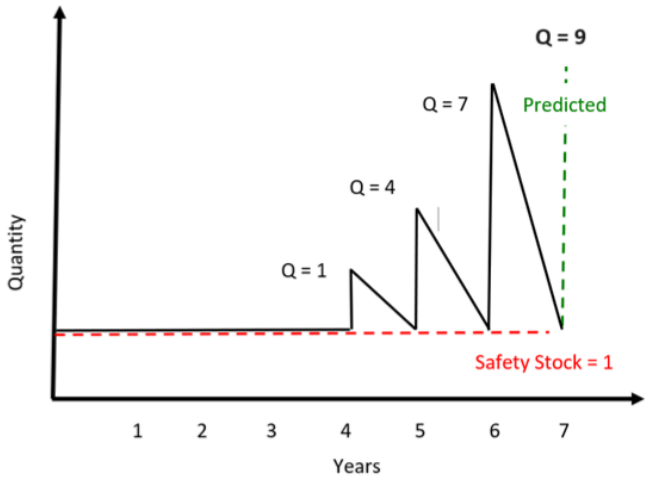

Figure 6. Order quantities and stock levels

5.3 Proposed Improvements

Vendor managed inventory (VMI) control safety stock of the buyer, so that vertical integration, and responsiveness are maintained to leverage customer service and improve the supply chain process. VMI transfers the risk and cost of storing and controlling parts to the vendor. This can free up resources for the company and improve efficiency. Safety stock is a buffer of inventory that can be used to cover unexpected demand. This can help to prevent stockouts and meet customer needs through replenishment to cover demand variations. For this case study, it was successful having VMI for the information to be transferred between company parties. This reduced reaction time and outsource maintenance costs. The benefit gained also was responding to customer demand and changes in the market. By implementing these improvements, the company has improved its supply chain efficiency, reduced costs, and met customers' needs more effectively.

6. Conclusion

Effective supply chain management plays a very important role to ensure the continuity of the services provided in residential complexes, and therefore stopping them or operating inappropriately will directly affect the satisfaction of the residents and affect the reputation and thus the commercial value and profits.

Accurate demand forecasting and proper VMI helped facility managers to:

- Reduce costs by avoiding the need to order and stock unnecessary parts.
- Avoid holding cost and inventory risk and transfer it to the supplier.
- Improve efficiency by ensuring that the right parts are available when they need them.
- Reduce downtime and disruptions to services.
- Improve resident satisfaction.

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References

Abdeen, F.N. and Sandanayake, Y.G., Facilities management supply chain: collaboration of FM functions, flows and parties in the apparel sector. *International Journal of Logistics Research and Applications*, pp.161-180, 2022.

Archer, B., Demand forecasting and estimation. *Demand forecasting and estimation.*, pp.77-85, 1987.

Babaveisi, V., Teimoury, E., Gholamian, M.R. and Rostami-Tabar, B., Integrated demand forecasting and planning model for repairable spare part: an empirical investigation. *International Journal of Production Research*, *61*(20), pp.6791-6807, 2023.

Brocks, M.P. and Trujillo Castañeda, R.E., *The impact of installed base and machine failure prediction on spare parts forecasting and inventory planning* (Doctoral dissertation, Massachusetts Institute of Technology), 2016.

Chawla, G. and Miceli, V., Demand Forecasting and Inventory Management for Spare Parts. 2019.

Hassan, J., Khan, F. and Hasan, M., A risk-based approach to manage non-repairable spare parts inventory. *Journal of quality in maintenance engineering*, *18*(3), pp.344-362. 2012.

Jang, R. and Collinge, W., Improving BIM asset and facilities management processes: A Mechanical and Electrical (M&E) contractor perspective. *Journal of Building Engineering*, *32*, p.101540., 2020

Karthika, D. and Karthikeyan, K., a Recent Review Article on Demand Forecasting. *Xi'an Univ Archit Technol*, *12*, pp.5769-77, 2020.

Mangano, G. and De Marco, A., The role of maintenance and facility management in logistics: a literature review. *Facilities*, *32*(5/6), pp.241-255, 2014.

Marquès, G., Thierry, C., Lamothe, J. and Gourc, D., A review of vendor managed inventory (VMI): from concept to processes. *Production Planning & Control*, *21*(6), pp.547-561, 2010.

Mohd-Lair, N.A., Pang, C.K., Liew, W.Y., Semui, H. and Yew, L.Z., An EOQ based multi-storage location of spare part inventories: A case study. *Applied Mechanics and Materials*, *315*, pp.733-738, 2013.

Nazali Mohd Noor, M. and Pitt, M.,The application of supply chain management and collaborative innovation in the delivery of facilities management services. *Journal of facilities management*, *7*(4), pp.283-297, 2009.

Rasolofo-Distler, F. and Distler, F., Using the balanced scorecard to manage service supply chain uncertainty, 2018.

Supplyon, Siemens China realizes efficient inventory management with SupplyOn, 2023. Retrieved from https://www.supplyon.com/en/blog/siemens-china-realizes-efficient-inventory-management-with-supplyon/.

Van den Toorn, T., Forecasting spare part demand: installed base concepts, failure rate function and varied expected lifetimes, 2020.

Biographies

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