

# Maintenance Workload Forecasting

# Maintenance Load



## Maintenance Load

- ❑ Maintenance forecasting and capacity planning are two important functions for the design of an effective maintenance system.
- ❑ Maintenance load forecasting comprises the estimation and predication of the maintenance load. This maintenance load represents the driving force of the whole maintenance system

## Forecasting Model

## Forecasting Techniques

# Maintenance Load

## Types of Maintenance Load :

- ❑ Planned maintenance works which involves all the works that are characterized by their ability to be planned and scheduled.
- ❑ Unplanned maintenance works which involves all works that are very difficult to be planned and scheduled. (These works depend primarily on the failure pattern and they are a major source of uncertainty in the planning process)

The sum of maintenance load in these two categories is a random variable and it is the major factor in determining the maintenance capacity.

# Maintenance Load



## Maintenance Load

Capacity Planning Involves the determination of the maintenance resources that are needed to meet the maintenance load in order to achieve the organizational objectives such as:

1. Availability
2. Reliability
3. Quality rates
4. Delivery dates

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**Maintenance Load**

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The Essential Element of the Capacity Planning is the determination of :

- ❑ Skills of craftsmen
- ❑ The exact number of various type of craftsmen
- ❑ Types of maintenance equipment and tools
- ❑ The exact number of maintenance equipment and tools
- ❑ Spare parts and materials
- ❑ The right level of backlog
- ❑ Overtime capacity
- ❑ Contract maintenance

# Forecasting Model

Forecasting techniques for determining maintenance load can be divided into:

- ❑ **Qualitative techniques**: based on the expert or engineering experience and judgment. Such techniques are:
  - Surveys
  - Delphi method: a group of experts respond individually to a questionnaire, providing forecasts and justifications. Results are combined, summarized, and returned to experts to revise. The process is repeated until consensus is reached
- ❑ **Quantitative techniques**: based on mathematical models that drive from historical data estimates for future trends. They are either time series- based (moving average) or structural (regression models).

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# Forecasting Model



The considerations used to select the forecasting technique are:

- ❑ The purpose of the forecast
- ❑ The time horizon for the forecast
- ❑ The availability of the data needed for particular technique.

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# Forecasting Model



The model is judged by the following criteria:

- ❑ **Accuracy** which is measured by how accurately the model predicts future values, and is judged by the difference between the model forecasts and the actual observed values.
- ❑ **Simplicity** of calculation, data needed, and storage requirements.
- ❑ **Flexibility** which is the ability to adjust to changes in conditions.

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## Qualitative Forecasting Techniques :

- ❑ These techniques are used when there is no historical data available.
- ❑ The way to forecast the value of an item is through relying on the estimates of experts and their judgment.

## The role of the analyst is to :

- ❑ Systematically extract information from the expert by using questionnaire and interviews.
- ❑ Help the expert to quantify his knowledge.
- ❑ Identify which variables influence the forecast and the impact of each one.
- ❑ Reach an agreement on the magnitude of the variables and use them to estimate the magnitude of the variables that affect the forecast.

## Quantitative Forecasting Techniques :

- ❑ These techniques are used when the historical data is available.
  
- ❑ The models uses these techniques assume either:
  1. Future values follow historical trends.
  2. A predictor (independent) variable exists that can provide a functional relationship that predicts (dependent) the characteristic under study.

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# Forecasting Techniques



## Types of Quantitative Forecasting Techniques:

- ❑ Simple Moving Average
- ❑ Weighted Moving Average
- ❑ Regression Analysis
- ❑ Exponential Smoothing
- ❑ Seasonal Forecasting

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## Seven Steps in Forecasting

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1. Determine the use of the forecast
2. Select the items to be forecasted
3. Determine the time horizon of the forecast
4. Select the forecasting model(s)
5. Gather the data
6. Make the forecast
7. Validate and implement results

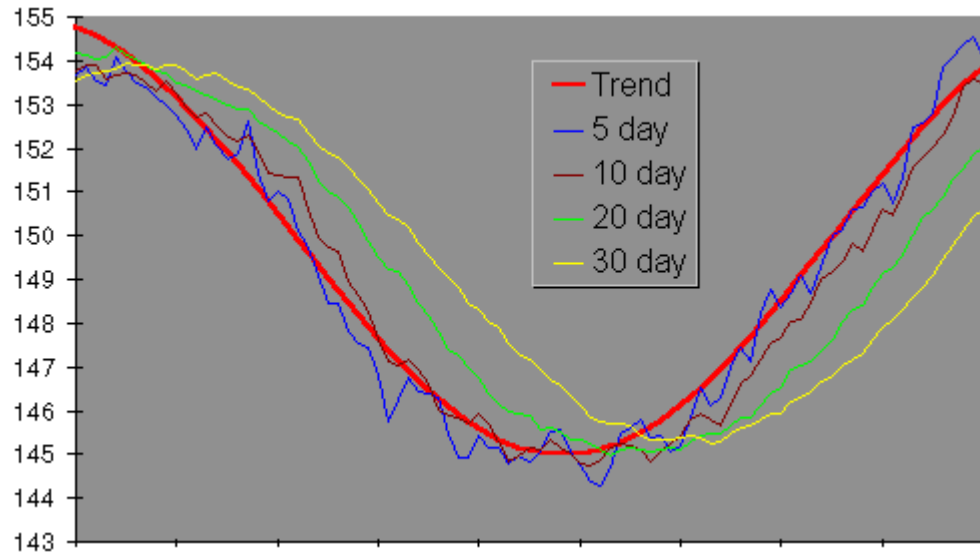
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## Moving Average Method

MA is a series of arithmetic means used if there is little or no trend and often for smoothing. It provides overall impression of data over time

$$MA = \frac{\sum \text{Demand in Previous } n \text{ Periods}}{n}$$

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## Moving Average Method (Example)

If the maintenance load in man-hours for the last 6 months is given as

Month	1	2	3	4	5	6
Maintenance Load	200	300	200	400	500	600

Find the load forecast for periods **7 and 8 using a 3 month moving average.**

The forecasted load for month 7 using is

$$\hat{x}_7 = \frac{400 + 500 + 600}{3} = 500$$

We did not observe  $x_7$ , so if the load in month 7 is estimated as 500 as calculated above The forecast for the 8th month is obtained as:

$$\hat{x}_8 = \frac{500 + 600 + 500}{3} = 533.33$$

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## Weighted Moving Average Method

- Used when trend is present
- Older data usually less important
- Weights based on experience and intuition

## Disadvantages of Moving Average Methods

- Increasing  $n$  makes forecast less sensitive to changes
- Do not forecast trend well
- Require much historical data

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## Weighted Moving Average Method

- Used when trend is present
- Older data usually less important
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$$\bar{x}_{n+1} = \sum_{i=1}^n w_i x_i$$

## Disadvantages of Moving Average Methods

- Increasing n makes forecast less sensitive to changes
- Do not forecast trend well
- Require much historical data

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## Weighted Moving Average Method

### Example

Find the load forecast for periods 7 and 8 using a 3 month weighted moving average

If  $w_5 = w_4 = 0.25 \quad w_6 = 0.5$

$$\hat{x}_7 = 0.25(400) + 0.25(500) + 0.5(600) = 525$$

$$\hat{x}_8 = 0.25(500) + 0.25(600) + 0.5(525) = 537.5$$

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## Exponential Smoothing Solution

Assigns weights to observations of previous periods in an inverse proportion to their age.

$$\hat{x}(t) = \alpha x(t - 1) + (1 - \alpha)\hat{x}(t - 1)$$

where

$\hat{x}(t)$  = the forecast for period t and all future periods in the case of a constant model.

$x(t - 1)$  = actual demand at period t-1

$\hat{x}(t - 1)$  = the forecasted value for t-1

$\alpha$  = smoothing constant,

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## Exponential Smoothing Example

If the maintenance load in man-hours for the last 6 months is given as

Month	1	2	3	4	5
Maintenance Load	800	600	900	700	600

Given that  $\alpha = 0.2$  and  $F_1 = D_1$ , apply simple exponential smoothing to the data to forecast maintenance workload in **month 6**

Data and intermediate calculations for the simple exponential smoothing example

$$\hat{x}(t) = \alpha x(t - 1) + (1 - \alpha)\hat{x}(t - 1)$$

- $F_1 = 800$
- $F_2 = 0.2(800) + 0.8(800) = 800$
- $F_3 = 0.2(600) + 0.8(800) = 760$
- $F_4 = 0.2(900) + 0.8(760) = 788$
- $F_5 = 0.2(700) + 0.8(788) = 770.4$
- $F_6 = 0.2(600) + 0.8(770.4) = 736.32$

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## Trend Projections

Fitting a trend line to historical data points to project into the medium-to-long-range

Linear trends can be found using the least squares technique

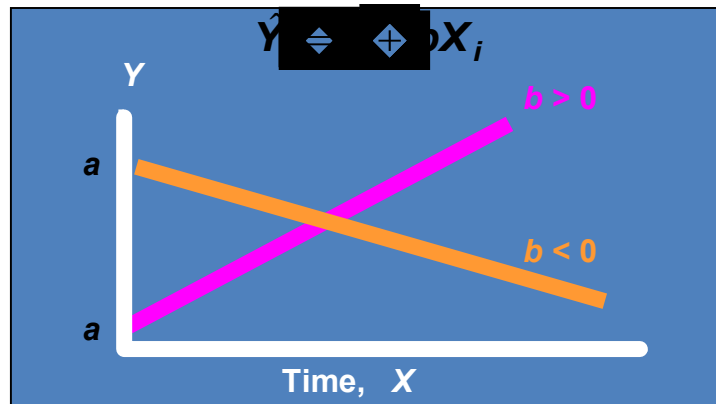
$$\hat{y} = a + bx$$

where  $\hat{y}$  = computed value of the variable to be predicted  
(dependent variable)

$a$  = y-axis intercept

$b$  = slope of the regression line

$x$  = the independent variable



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# Forecasting Techniques



Equations to calculate the regression variables

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$$x(t) = \hat{a} + \hat{b}t$$
$$\hat{b} = \frac{n \sum_{t=1}^n tx(t) - \left( \sum_{i=1}^n t \right) \left( \sum_{t=1}^n x(t) \right)}{n \sum_{t=1}^n t^2 - \left( \sum_{t=1}^n t \right)^2}$$
$$\hat{a} = \bar{x} - \hat{b}\bar{t}$$

# Forecasting Techniques



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**Example:** Demand for a given spare part is given below for the last 4 years. Use linear regression to determine the best-fit straight line and to forecast spare part demand in year 5

Year t	1	2	3	4
Spare part demand D(t)	100	120	150	170

Intermediate calculations for the linear regression example

					<b>Sum</b>
<b>t</b>	1	2	3	4	10
<b>D(t)</b>	100	120	150	170	540
<b>tD(t)</b>	100	240	450	680	1470
<b>t<sup>2</sup></b>	1	4	9	16	30

$$b = \frac{4(1470) - 10(540)}{4(30) - 10^2} = 24$$

$$a = \frac{1}{4} [540 - 24(10)] = 75$$

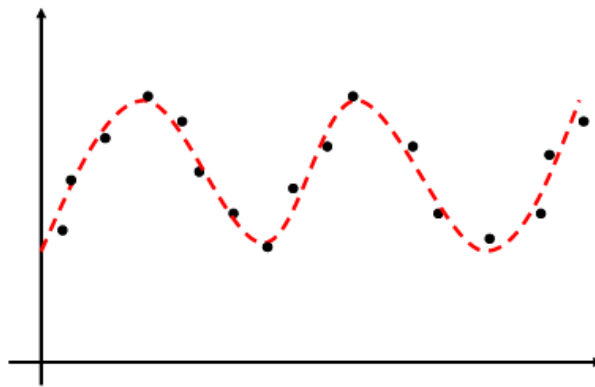
$$D(t) = 75 + 24t$$

$$D(5) = 75 + 24(5) = 195 \text{ units}$$

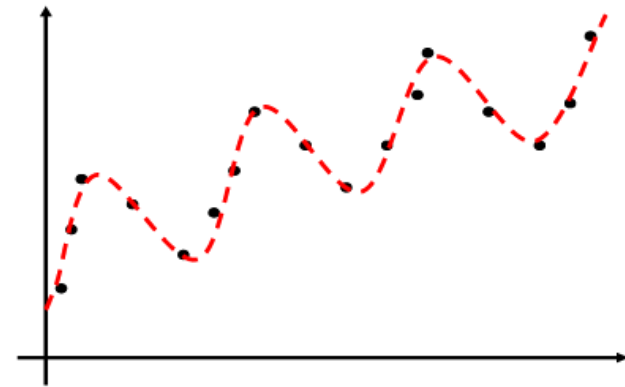
# Forecasting Techniques

## Seasonal Forecasting

- ❑ The demand for many products and services may follow a seasonal or cyclic pattern, which repeats itself every N periods.
- ❑ Maintenance workload may show seasonal variation due to periodic changes in demand, weather, or operational conditions



Seasonal pattern



Seasonal-trend pattern

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## Forecasting for Stationary Seasonal Data

1. Calculate the overall average  $\mu$ ;
2. Divide each point by the average  $\mu$  to obtain seasonal factor estimate;
3. Calculate seasonal factors  $c_t$  by averaging all factors for similar periods;  $c_t$  = seasonal factor (multiplier) for time period  $t$ ,  $1 \leq t \leq N$ ,
4. Forecast by multiplying  $\mu$  with the corresponding  $c_t$  for the given period.

### Example

The quarterly totals of maintenance work orders are given below for the last 3 years. Forecast the number of maintenance work orders required per quarter in year 4

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Year 1	7,000	3,500	3,000	5,000
Year 2	6,000	4,000	2,500	5,500
Year 3	6,500	4,500	2,000	4,500

# Forecasting Techniques



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**Step 1-** sum of all data = 54,000

Overall average  $\mu = 54,000/12 = 4,500$

**Step 2 and 3-** dividing data by 4,500 and averaging columns gives the values in the following table

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Year 1	1.5556	0.7778	0.6667	1.1111
Year 2	1.3333	0.8889	0.5556	1.2222
Year 3	1.4444	1	0.4444	1
Average = $c_t$	1.4444	0.8889	0.5556	1.1111

Note that sum of the four seasonal factors (1.4444 + ... + 1.111) is equal to 4, which is the length of the cycle N (four quarters).

**Step 4-** finally, the forecasted maintenance work orders for each quarter in year 4 are given by

- $F_1 = 1.4444(4,500) \cong 6,500$  Quarter 1
- $F_2 = 0.8889(4,500) \cong 4,000$  Quarter 2
- $F_3 = 0.5556(4,500) \cong 2,500$  Quarter 3
- $F_4 = 1.1111(4,500) \cong 5,000$  Quarter 4

## Forecasting for Seasonal Data with a Trend

The usual approach to forecast with seasonal-trend data is to estimate each component by trying to remove the effect of the other one. The approach to do that include: (1) remove trend to estimate seasonality, (2) remove seasonality to estimate trend, and (3) forecast using both seasonality and trend.

1. Divide each cycle by its corresponding cycle average to remove trend.
2. Average the de-trended values for similar periods to determine seasonal factors  $c_1, \dots, c_N$ . If  $\sum c_t \neq N$ , normalize seasonal factors by multiplying them with  $N/\sum c_t$ .
3. Use any appropriate trend-based method to forecast cycle averages.
4. Forecast by multiplying the trend-based cycle average by appropriate seasonal factor.

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# Forecasting Techniques



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## Example

For a university maintenance department, the number of work orders per academic term is given below for the last 3 years. Forecast the number of maintenance work orders required per term in year 4.

	Term 1	Term 2	Term 3 (summer)
Year 1	10,000	7,000	5,000
Year 2	12,000	8,000	6,000
Year 3	14,000	9,000	7,000

Calculations for seasonal factors (steps 1 and 2) are shown in following tables:  
Calculating cycle averages

Term: $t$ Year: $d$	1	2	3	Cycle (year) Sum	Cycle average: $A_d$
1	10,000	7,000	5,000	22,000	7,333.33
2	12,000	8,000	6,000	26,000	8,666.67
3	14,000	9,000	7,000	30,000	10,000

# Forecasting Techniques



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Calculating seasonal factors by dividing by cycle averages

Term: $t$ Year: $d$	1	2	3
1	1.364	0.955	0.682
2	1.385	0.923	0.692
3	1.400	0.900	0.700
<b>Average = <math>c_t</math></b>	1.383	0.926	0.691

There is no need to normalize seasonal factors since their sum (1.383 + 0.926 + 0.691) is equal to 3, which is the length of the cycle N (three terms). Using regression, calculations for the trend components of cycle averages (step 3)

	$d$	$A_d$	$dA_d$	$d^2$
	1	7,333.33	7,333.33	1
	2	8,666.67	17,333.33	4
	3	10,000	30,000	9
Sum	6	26,000	54,666.67	14

# Forecasting Techniques



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$$b = \frac{3(54,666.67) - 6(26,000)}{3(14) - 6^2} = 1,333.33$$

$$a = \frac{1}{3} [26,000 - 1,333.33(6)] \cong 6,000$$

Forecasting Model

The forecasting model for period (term) t of cycle (year) d is given by  
 $F_{d, t} = c_t[6,000 + 1,333.33d]$

Forecasted maintenance work orders required per term in year 4 are calculated as

$F_{4, 1} = 1.383[6,000 + 1,333.33(4)] = 15,674$	Term 1
$F_{4, 2} = 0.926[6,000 + 1,333.33(4)] = 10,495$	Term 2
$F_{4, 3} = 0.691[6,000 + 1,333.33(4)] = 7,831$	Term 3

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## Error Analysis

The following error measures are commonly used for error analysis and evaluation of forecasting models

1. Mean Absolute Deviation (MAD)

$$MAD = \frac{\sum_{t=1}^N |x(t) - \hat{x}(t)|}{N}$$

2. Mean Squared Error (MSE)

$$MSE = \frac{\sum_{t=1}^N (x(t) - \hat{x}(t))^2}{N}$$

3. Mean Absolute Percent Error (MAPE)

$$MAPE = \frac{100}{N} \sum_{t=1}^N \left[ \left| \frac{x(t) - \hat{x}(t)}{x(t)} \right| \right]$$

4. Mean Squared Percent Error (MSPE)

$$MSPE = \frac{100}{N} \sum_{t=1}^N \left[ \left( \frac{x(t) - \hat{x}(t)}{x(t)} \right)^2 \right]$$

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# Forecasting Techniques



A company wants to predict the maintenance workload of its mechanics for the first period of the next year. Before the company does that, it has been noted that in the first period of the next year, the company manufacturing plant will pass over circumstances similar to those that it faced in the first six months of the last year. What is the mechanics maintenance workload for the first period of the next year if the actual maintenance workloads for these mechanics in the previous periods are given in the following table ?

**Example**

Periods	Actual Maintenance Workload (hours)	Periods	Maintenance Workload (hours)
1	120	7	111
2	100	8	130
3	110	9	110
4	90	10	125
5	95	11	120
6	105	12	100

# Forecasting Techniques

A manufacturing plant wants to predict the maintenance work load of its electricians for the next planning period in one of its manufacturing area. The engineers in the maintenance department found that during the last six periods, a percentage of the actual maintenance workload performed during each one of these periods represents a part of the forecasted maintenance work load for the electricians in the next planning period. In particular, they found the following:

1. 22% of the actual maintenance work load in the first period of the last six periods represents the first part of the forecasted maintenance work load of the electricians.
2. 18% of the actual maintenance work load in the second period of the last six periods represents the second part of the forecasted maintenance work load of the electricians.
3. 15% of the actual maintenance workload in the other remaining periods represents the remaining parts of the forecasted maintenance work load of the electricians
4. The actual maintenance workloads in the previous periods are given in the following table

## Example

# Forecasting Techniques



Periods	Actual Maintenance Workload (hours)
1	150
2	130
3	160
4	100
5	130
6	110

Example

# Forecasting Techniques



Calculate the next planning period maintenance workload for a manufacturing area in a plant that has 12 machines, if the recent actual maintenance workloads reflect only 40% of the amount of this manufacturing area next period maintenance workload. The actual maintenance workloads in the previous periods are given in the following table

Periods	Actual Maintenance Workload (hours)
1	30
2	37
3	25
4	35
5	20

**Example**

# Forecasting Techniques



A company wants to predict the maintenance workload for the next planning period for one of its manufacturing area. The area has six machines in total. It started its production in the first two periods by using two of these six machines. After that, all of the six machines were operated to cover the production demand. These six machines will still be operated in the next planning period. The actual maintenance workloads in the previous periods for the same area are given in the following table 4. Find the next planning period maintenance workload.

**Example**

Periods	Actual Maintenance Workload (hours)	Periods	Actual Maintenance Workload (hours)
1	60	7	327
2	50	8	320
3	360	9	316
4	345	10	312
5	336	11	305
6	330	12	300