# Breakdowns Happen: How to Factor Downtime into your Simulation

*"One of the most debatable pieces of data that goes into a simulation is the stochastic behavior of machine downtime".*

**Simulation expert Brian Harrington explains the key learning points simulation modelers should consider when working with downtime.**

Early in my career at Ford Motor Company as a simulation engineer I remember building simulations of our plants and wondering what values to put in for the downtime. In addition, I was also unsure of what distributions to use or why there were default distributions within the software. What was the impact of populating the simulation with breakdown behavior? It didn't take long to realize that downtime had significant effects upon the overall throughput. This article explains the key factors that should be considered when working with breakdowns within your simulation.

When considering downtime, the starting point should be to consider the following questions (see Appendix A for definitions):

1. How often does a machine fail (MTBF)?
2. How long does it take to repair it (MTTR)?

These two questions may seem simple, however are often abstracted within the forest of machinery and clouded by human behaviour. When a breakdown occurs on a machine, it's likely there is time associated with certain phases of a typical repair such as; reaction time, lockout procedure, actual repair and the start-up.

These repair phases are sources of large variation that can make the determination of a realistic MTBF & MTTR difficult. Why is "Availability" such an important piece of data? Because it causes random loses of potential 'working time'; which in turn can cause losses of overall system throughput. These breakdowns cause "Performance" issues within the system; often captured within the following two states: "Wait" and "Block".

Once a team enters downtime figures into their simulation they become concrete (at least for the particular scenario).  Downtime figures will always reduce the respective machines capability and cause potential performance issues with adjacent machinery, or worse yet a bottleneck.  Hence, companies might have to work additional overtime hours to make up for the lost capacity. In this paper we will explore some of the most useful considerations when deciding on realistic downtime data for a typical manufacturing simulation.

## Capture downtime at station or line level?

A key consideration when building a simulation is whether to record downtime at the station or line level. The recommendation is to align it with safety lockout zones. A facility might have a lockout procedure that shuts down a line, or zone within a line, when a repairman enters the zone. Often lockout zones are based on the electrical drops that are powering the lines. For example, an automotive line might have 8-stations with 2-lockout zones (see Figure 1). Therefore, when a fault occurs within a particular station the entire lockout zone will go down. This is easily captured within SIMUL8 using “Groups” and “Multiple Breakdowns”.

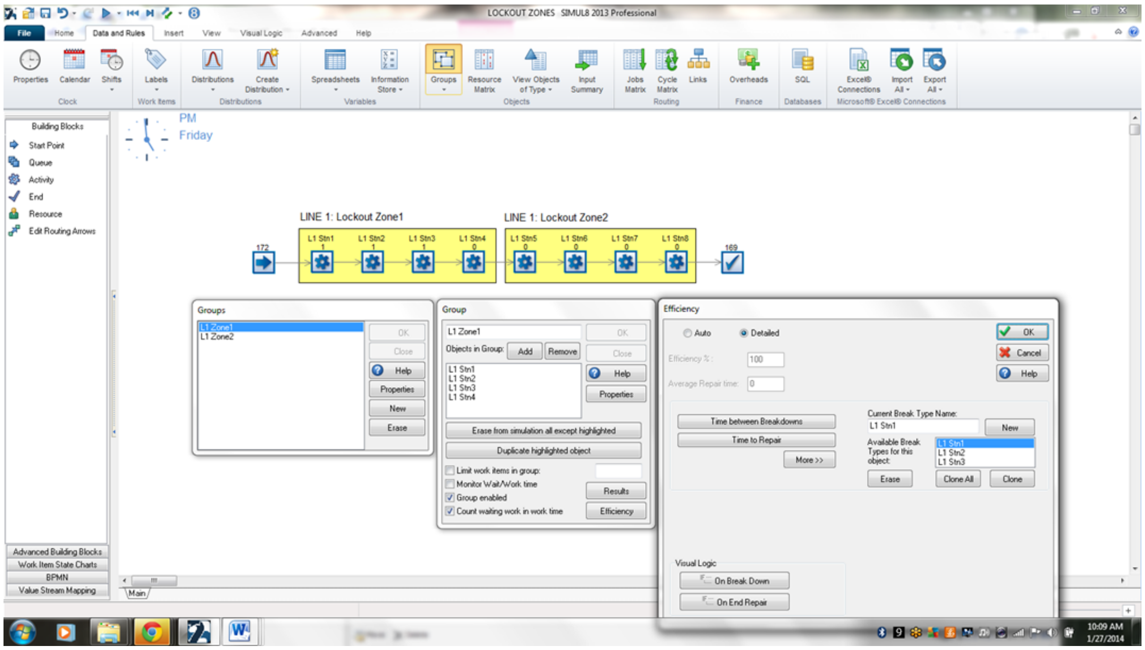



Figure 1: Using Groups and Multiple Breakdowns.

The above example uses downtime data at the station level, but it is captured within the Group which represents the Lockout zone. The same effect could also be accomplished without using “multiple breakdowns” by rolling up all the respective downtimes into one aggregate value. This technique would assume that you have access to the station level data and would simply use the mathematical calculations in the box below (see also Appendix A). Industrial engineers often use these equations at the component level to calculate MTBF and MTTR values for stations based on the stations content such as; number of robots, number of end-effectors and number of clamps that have been designed into the station.

$$\text{Failure Rate}_{\text{Zone1}} = (1/\text{MTBF}_1 + 1/\text{MTBF}_2 + 1/\text{MTBF}_3 + 1/\text{MTBF}_4)$$

$$\text{MTBF}_{\text{Zone1}} = 1/\ \text{Failure Rate}_{\text{Zone1}}$$

$$\text{Availability}_{\text{Zone1}} = \text{MTBF}_1/(\text{MTBF}_1+\text{MTTR}_1) * \text{MTBF}_2/(\text{MTBF}_2+\text{MTTR}_2) * \text{MTBF}_3/(\text{MTBF}_3+\text{MTTR}_3) * \text{MTBF}_4/(\text{MTBF}_4+\text{MTTR}_4)$$

$$\text{MTTR}_{\text{Zone1}} = \text{MTBF}_{\text{Zone1}}/(\text{Avail}_{\text{Zone1}} - \text{MTBF}_{\text{Zone1}})$$

The above calculations can be accomplished using Microsoft Excel.

In this following example we roll up the four station downtime figures into one aggregate value for Availability=90.07, and would use the two calculated values: MTBF= 60.23 & MTTR= 6.64.

**Multiple Breakdowns vs. Aggregate Value**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Station Name** | L1 Stn1 | L1 Stn2 | L1 Stn3 | L1 Stn4 | | | | | | | | | | | | **Total (Aggregate Values)** |
| **Failure Rate** | 0.003509 | 0.008333 | 0.001905 | 0.002857 | | | | | | | | | | | | 0.016604 |
| **MTBF (Min)** | 285.00 | 120.00 | 525.00 | 350.00 | | | | | | | | | | | | **60.23** |
| **MTTR (Min)** | 7.00 | 5.25 | 9.00 | 7.25 | | | | | | | | | | | | **6.64** |
| **Availability %** | 97.603% | 95.808% | 98.315% | 97.971% | | | | | | | | | | | | **90.070%** |

Figure 2: Table showing station downtime as one aggregate value.

Surprisingly, both techniques will provide statistically equivalent results. It is therefore recommended to use either approach based on the overall agreement of the simulation team. The below example simulation (Figure 3) demonstrates an Activity using seven multiple breakdowns compared against a similar Activity using one "Total Aggregate" value for its downtime values. The "KPI Summary" is based on one trail consisting of 12 runs, generating an overlapping confidence interval for the depicted throughput.

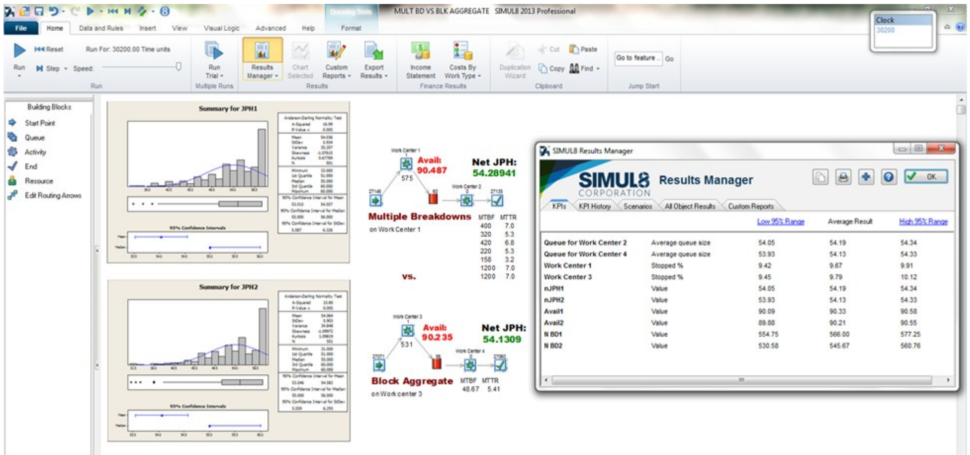



Figure 3: Simulation showing seven multiple breakdowns

## What distributions are associated with MTBF & MTTR?

It is recommended to use the widely recognized Exponential and Erlang distributions. These are proven shapes that capture the randomness, range and provide realistic samples around the mean. If we examine an Exponential Distribution using SIMUL8's "Stat::Fit" we can see what a typical curve might resemble for a MTBF. Notice when the standard deviation and mean are statistically equivalent we have an Exponential distribution (Figure 4).

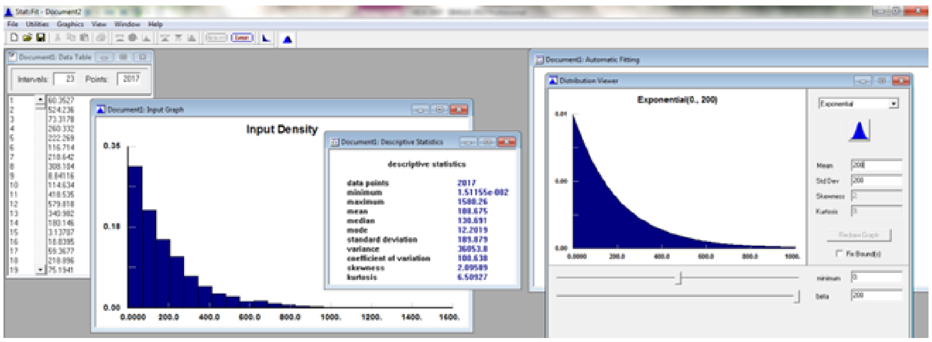



Figure 4: Exponential distribution.

Now that we have a curve that represents how often a failure occurs. Let's look at what shape would be appropriate to capture: "How long does it take to repair?" This is where the Erlang distribution fits; it has a shape parameter that creates a nicely skewed distribution which again captures a wide range of typical repair times. The below example uses "Stat::Fit" to examine a typical repair time of 7 minutes. Notice that the Erlang can provide samples that reach out towards possible catastrophic samples such as 40 minutes (see Figure 5). This type of curve provides the shape that mirrors many realistic repair times. There are many values that fall below the mean which capture the minor occurrences, i.e. setting a reset button. The skewed tail provide samples which require more sophisticated repair actions such as; possible electricians, millwrights, etc. When using the Erlang distribution for repair times the shape parameter "k" is often set to 2 or 3.

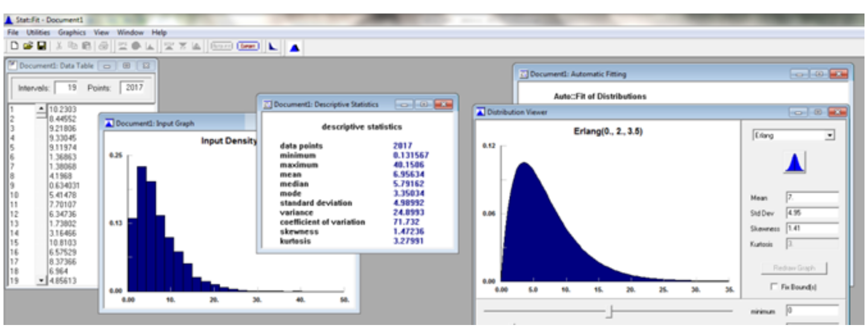



Figure 5: Erlang distribution.

## What about the time to react & travel?

We had mentioned that some simulation teams might want to include the time to react and travel to the faulted line. This can be accomplished with SIMUL8's "Combination" Distribution, which in this case would use two named distributions. The first distribution represents the repair time; and the second distribution captures the time to react & travel. The time to react & travel might be captured using a normal distribution with an average of 3 minutes. The "Combination" Distribution simply adds the two respective sample values together for a total value (Figure 6). The combination distribution allows the user to add as many "Named" distribution as desired. Therefore, you could even use an additional distribution splitting up the reaction and travel time.

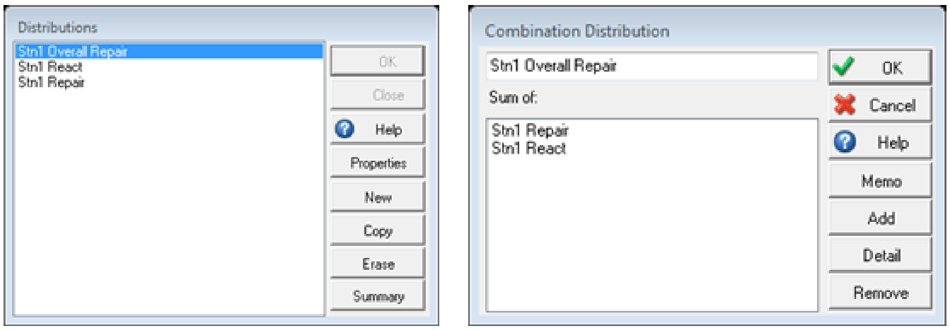



Figure 6: Combination distribution.

## How do we account for the Lockout Procedure?

A lockout procedure might be assumed to be followed on the lengthier repairs such as repair times that take 10 minutes or more. For example the lockout procedure time could be represented as a Normal Distribution using an average of 3 minutes and a standard deviation of 2.5. Hence, the average of 3 minutes would be added to all repair times that are greater or equal to 10. This will capture the time to lockout the equipment according to the companies safety protocol. The resulting distribution will be in the form of a bimodal distribution, where you will distinctly see the Erlangs' tail values pick up the additional lockout time (Figure 7). This type of bi-modal distribution can be created in a separate simulation model; which uses the referenced Visual Logic on Time Check. The Time Check is invoked every minute, and the simulation runs for 2000 minutes; thereby producing 2000 samples within a spreadsheet. The spreadsheet can then be copied into a Probability Profile distribution within the overall simulation; capturing a particular lockout procedure.

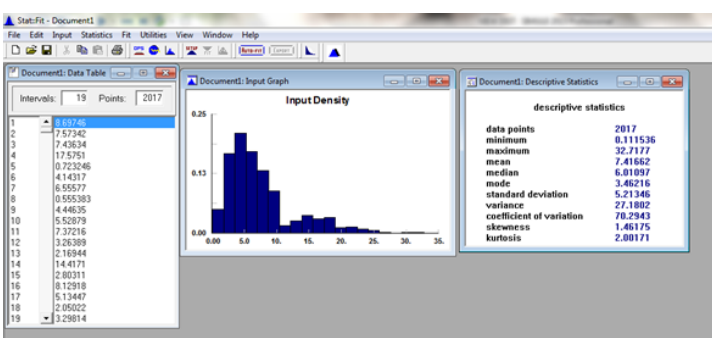



Figure 7: Bimodal distribution.

The bimodal distribution above was created using the following “Visual Logic”:

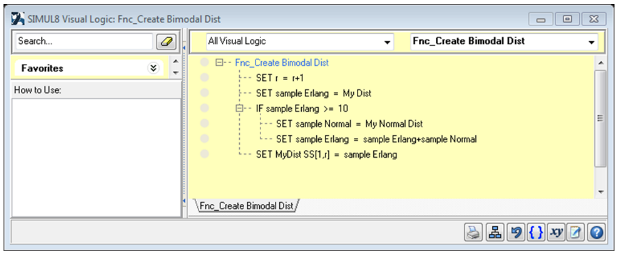
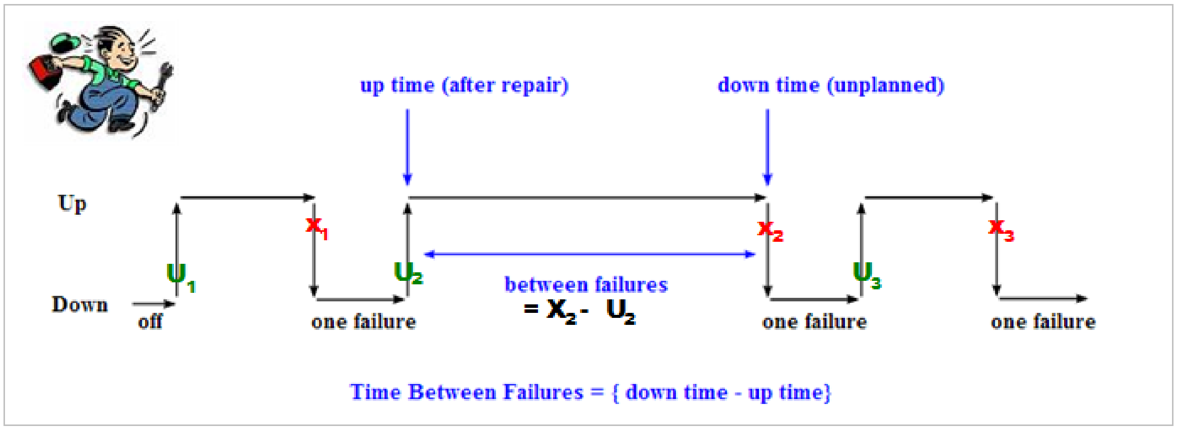



Figure 8: Visual Logic for bimodal distribution

## Don’t let Breakdowns get you down.

The data collection phase of simulations usually is the most time consuming piece of the pie; and downtime data can be some of the most difficult data to collect. The good news is that if the team puts faith in the use of statistical distributions, and proven simulation techniques, the debates on downtime figures can be reduced. The governing “Availability” of a particular line should always be what is addressed and agreed upon first; then the team can drill down further into the data and supporting explanations.  It’s recommended to hone in on your targeted “Availability”, then your targeted repair time (MTTR); then you can calculate your respective (MTBF). The important piece of advice is to leverage the known statistical distributions and keep the simulation development moving forward! The downtime parameters can always be updated.

# Appendix A




**MTBF = Total uptime for a period of time / number of stops during the same period**

MTBF: Mean Time Between Failures. By default based on Clock time this option stops a machine working at intervals based on the distributions used. The default in SIMUL8 is to breakdown an Activity based on the elapsed time since the end of repair for the previous breakdown.

$$\text{MTBF} = \frac{\sum \text{(Start of Downtime - Start of Uptime)}}{\text{Num of Failures}}$$

**MTTR = Total downtime for the same period as used for MTBF / number of Failures**

MTTR = Total downtime for the same period as used for MTBF / number of Failures

MTTR is the average time of a failure

$$\text{MTTR} = \frac{\sum \text{(Start of Uptime - Start of Downtime)}}{\text{Num of Failures}}$$

$$\text{Availability} = \text{MTBF} / [\text{MTBF} + \text{MTTR}]$$