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# Monte Carlo Simulations for Project Managers

**Nick Shyamani | Digital Six Sigma Black Belt**
**MOTOROLA SOLUTIONS**

# OUTLINE

- **Introduction to Monte Carlo Simulation**
  - What is Monte Carlo simulation,
  - When can we use it
  - Introduction to distributions
- **Monte Carlo Simulation usage examples**
  - For Schedules
  - For Portfolio Allocation &
    - Project Cost Planning
    - Capital investments etc
  - For Resources Planning
  - For Quality

# BASIC CONCEPT

$$Y = F(x_1, x_2, x_3 \ldots)$$

Results that matter

Key drivers of performance

Any relationship "**F**" that converts the values of a set of inputs into the value of an output, is called a *Transfer Function.*

# SIMULATION . . .

**Can be used to test new concepts and/or systems without actual implementation.**

- To address cost, schedule, staffing, scope, portfolio, quality & safety issues ….

**Provides an "insurance policy" for system performance**

- Think about the unthinkable
- By identifying outcomes which will only rarely be experienced in practice
  - example impacts of catastrophic failures, critical staff shortages, critical parts shortages, impact of delaying one deliverable to overall profitability of the portfolio etc.

**The most common form of simulation is called *Monte Carlo Simulation.***

# MONTE CARLO SIMULATION – HIGH LEVEL DESCRIPTION IN - MBA / BLACK BELT TALK

**Computer–generated random numbers can be used to simulate product or process variability.**

**Used in conjunction with transfer functions, this approach can evaluate the variability of many quantities of interest–even those with statistical properties too difficult to calculate directly.**

**Because the probability calculations underlying this method were originally studied in a gambling context, the developers of this technique dubbed it "Monte Carlo".**

# BOTTOM LINE: MONTE CARLO SIMULATION

**Primary Use:**

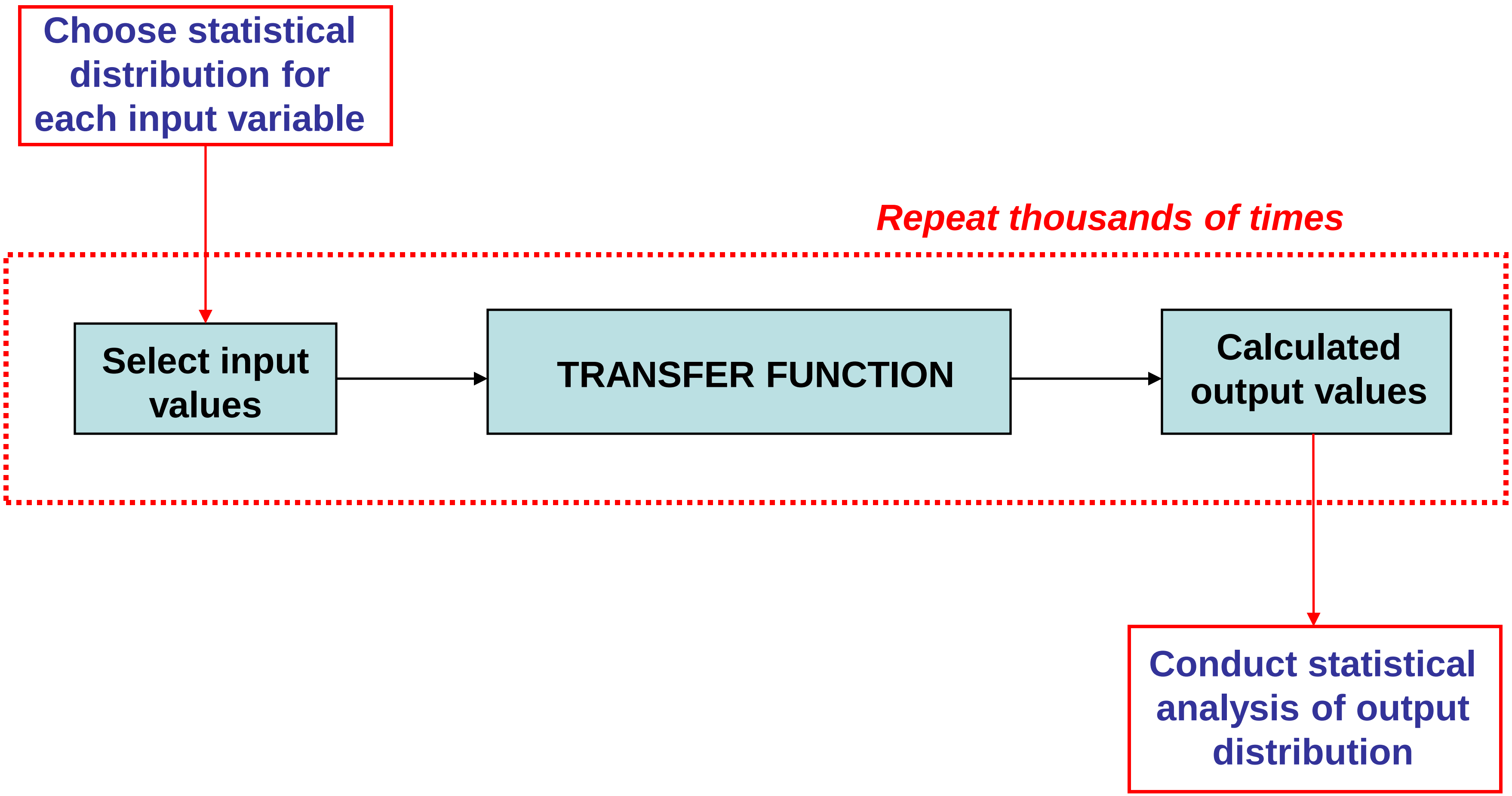
**Use** Monte **Carlo to calculate the probability of success.**

**In the hands of Project Manager:**

Use to Maximize probability of success by :

- Identifying the highest risks
- Focusing on the most important risks first
- Creating mitigation actions to reduce variability of critical risks to improve the projects success probability.
  (Remember the BIG Y – What is really important)

# Monte Carlo Simulation



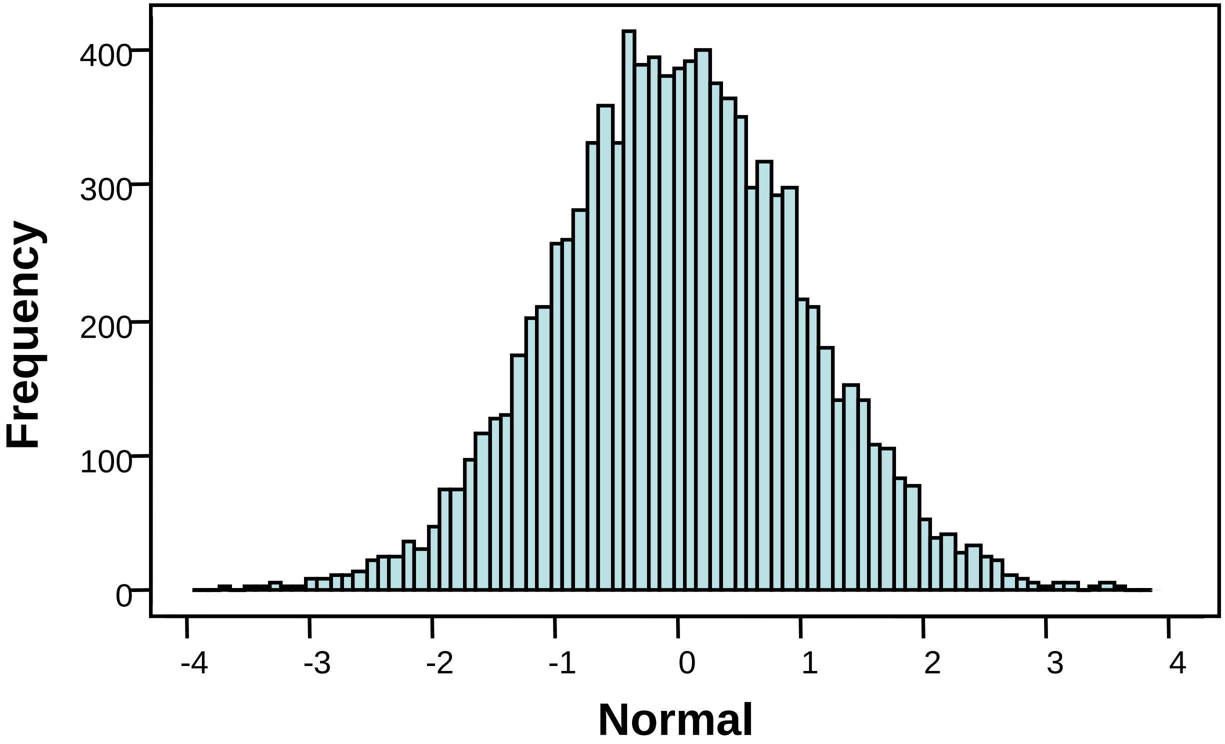
# INPUT DISTRIBUTIONS

**Most statistical analysis assumes that input variability is Normally distributed.**

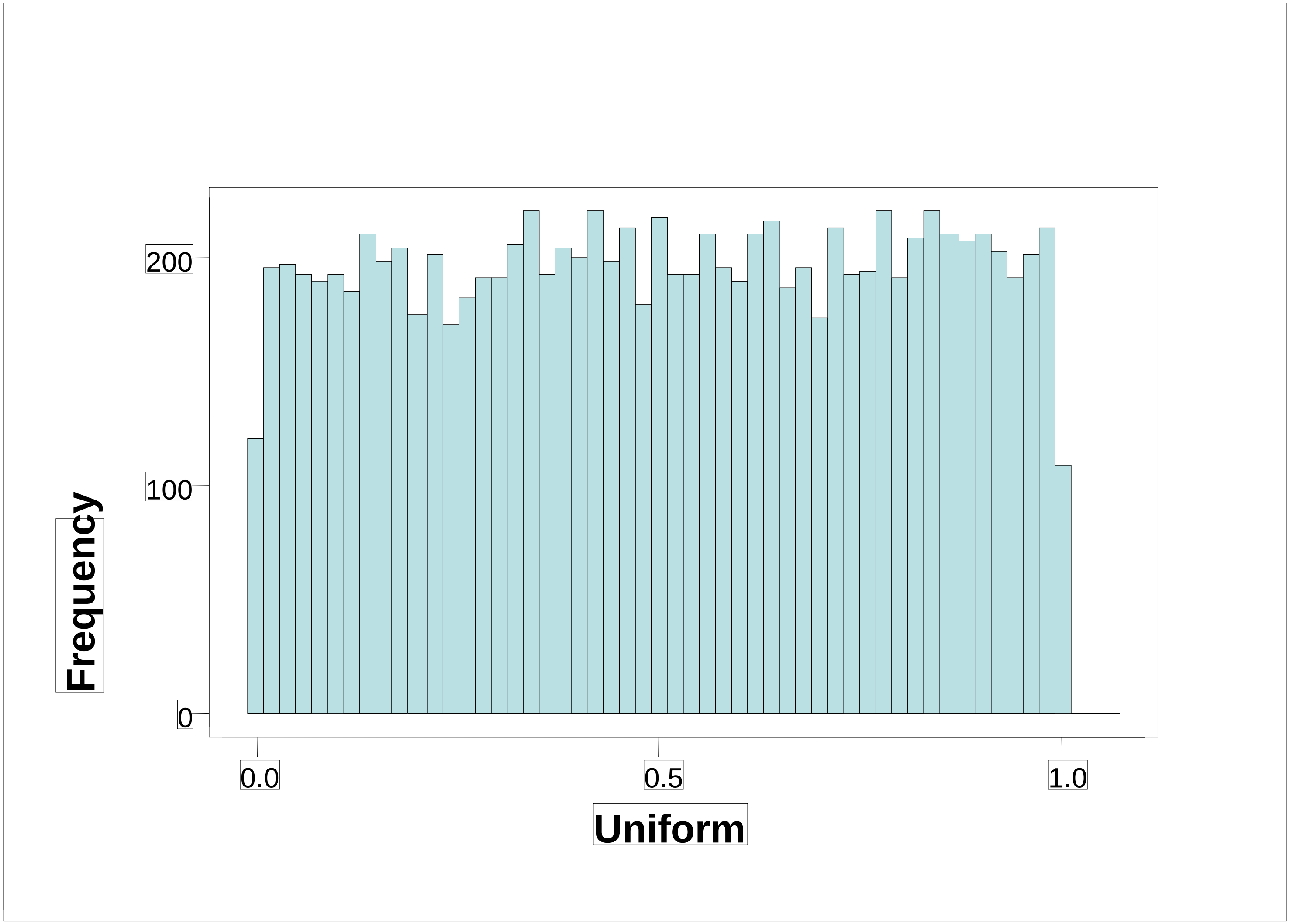
**In other cases, it may be more realistic to use other distributions, e.g.:**

- Exponential, for inter-arrival times
- Weibull, for component life/failure times
- Lognormal, for cycle times
- Poisson, for the number of events in a given time interval
- Triangular distribution

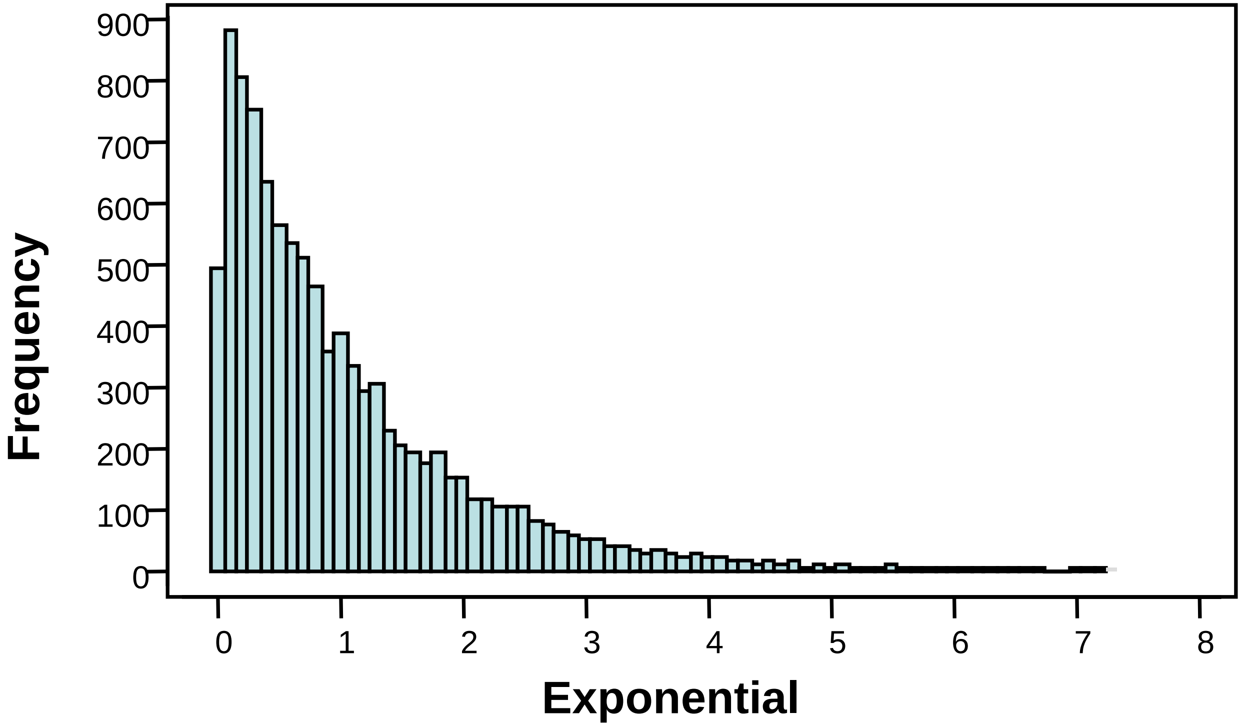
# HISTOGRAM OF NORMAL DISTRIBUTION



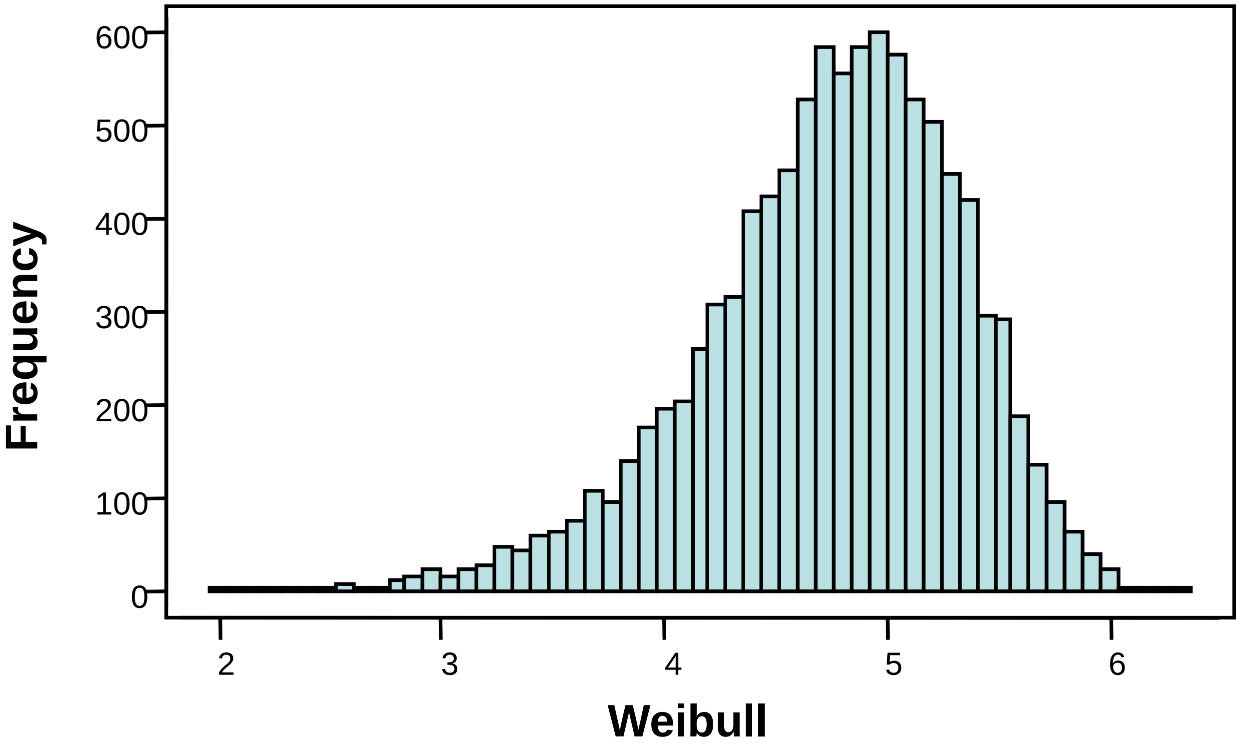
# HISTOGRAM OF UNIFORM DISTRIBUTION



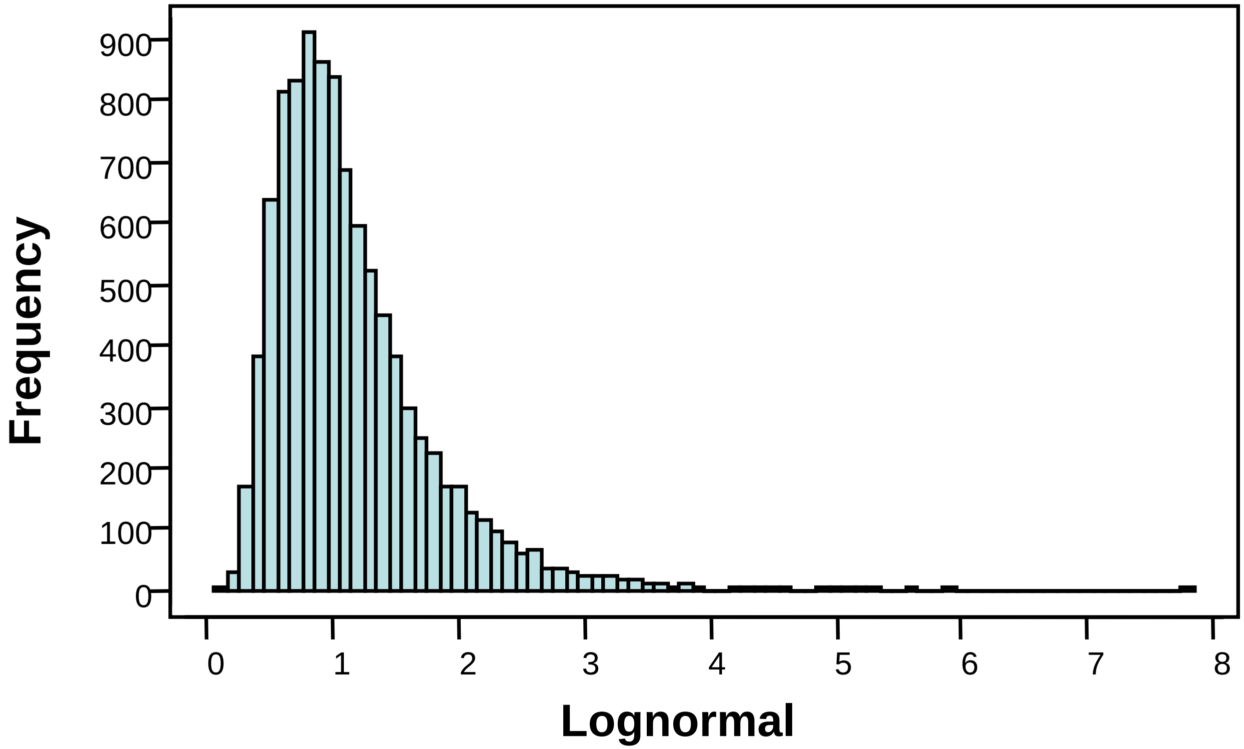
# HISTOGRAM OF EXPONENTIAL DISTRIBUTION



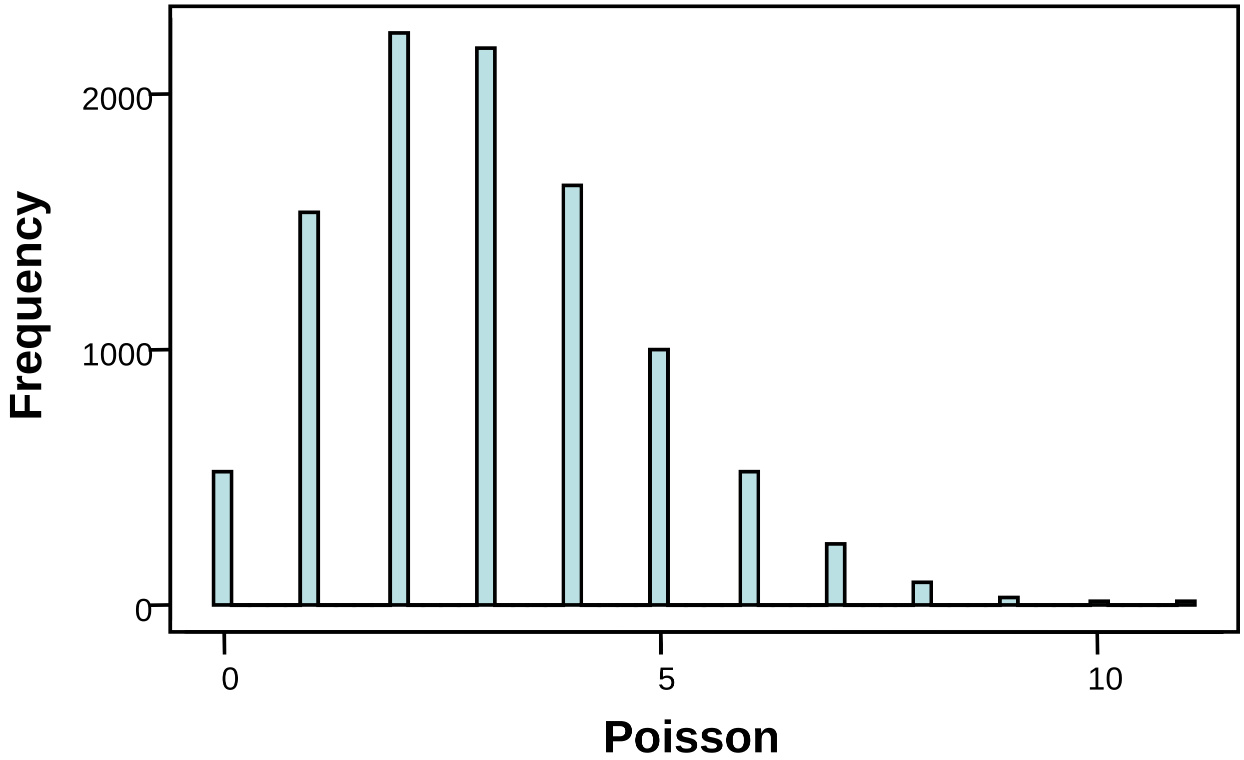
# HISTOGRAM OF WEIBULL DISTRIBUTION



# HISTOGRAM OF LOGNORMAL DISTRIBUTION



# HISTOGRAM OF POISSON DISTRIBUTION



# WHAT TO USE WHEN YOU'RE NOT SURE? USE THE BEST DISTRIBUTION AVAILABLE ..

| | |
|---|---|
| **Distributions which have known realistic properties** | •From historical projects, or industry standards |
| **Uniform Distribution** | •Can be used when only min and max are available<br>•Captures the idea of complete uncertainty over the specified range of values<br>•Requires a 2 point estimate from experts |
| **Triangular Distribution** | •Can be used when only min, max and most likely are available<br>•Requires 3 point estimates from experts |
| **Often a good idea to try several to determine sensitivity–does distribution really matter?** | • Advantage of simulations: low cost to test your assumptions,<br>• Confirm the sensitive of assumption changes on the final outcome. |
| Evaluate the impacts of changing the assumptions on the outcomes. | • Do I really need to worry about this assumption?<br>• Does the final outcome change a lot by improving the variability of this assumption? |

# Crystal Ball - MONTE CARLO SIMULATIONS EXAMPLE
# Critical Path / Time to Market Analysis

## Summary

This model analyzes the process, project schedule, or time it would take to get a product to market, with the goal of understanding how uncertainty affects project completion.

At the bottom of the Model worksheet, a diagram depicts the flow pattern of the tasks. The results of this model indicate the likelihood that any particular task will be on the critical path, and the model can then be used to evaluate which pivotal tasks should be addressed to improve the results for the entire project.

## Discussion

A flow chart on the Model worksheet shows the project sequence. The task durations are triangular assumptions based on the best estimate of the project manager. In addition, various predecessors bound when subsequent tasks can begin. As in the flow chart, the formulas in the worksheet determine the earliest and latest starting and finishing times for each task, including the lag or lead entered in the spreadsheet for that particular step.

When the simulation runs, the model performs a forward and backward pass, indicating in each trial whether or not a given task was on the critical path. After running a complete simulation, you can determine the likelihood that any particular task is on the critical path of the project. The model also calculates the days of slack for each step, and formats the cells for those steps on the critical path with a dark blue background (using conditional formatting.)

Please note that, while there are other software packages that specifically perform project analysis, Crystal Ball and Excel can be used to achieve the same goal.

- From Crystal Ball examples

# Crystal Ball - MONTE CARLO SIMULATIONS EXAMPLE
# Project Cost Estimation

## Summary

This simple spreadsheet model estimates the cost of replacing an air filtration system at a major manufacturing plant. You have prepared a traditional contingency analysis, but are concerned that a bid of $82 million will significantly reduce your chances of winning the project.

Your task is to find the lowest amount your company can bid, while remaining confident that there is only a 5% chance of exceeding your estimated costs and losing money on the project.

## Discussion

Most projects overrun the base cost estimate because of factors outside the control of even the most competent project manager. The sources of these over runs are numerous and it is important to develop an accurate contingency budget.

One common practice is to create a contingency percentage for each line item in the budget. This practice can lead to overestimating costs if the individual elements are all summed at the worst case scenario

- From Crystal Ball examples

# Crystal Ball - MONTE CARLO SIMULATIONS EXAMPLE
# Workforce Planning with Queuing

## Summary


Businesses that serve customers in queues typically need to balance their staff size with customer expectations. As more servers are available, each customer spends less time waiting in line. However, the cost to employ these additional servers must also be considered.

Many businesses have the capacity to hire servers with varying levels of training, experience, and speed in service. The problem is to minimize costs while ensuring that customer requirements are met.

In this example, we refer to the servers as tellers; however, they could also be checkers, waiters, or toll-booth attendants, among others.


## Discussion

This model was built for a business that has the opportunity to have up to five lines in service at once. The model will help them determine the appropriate number of lines to have open and what level of employees should be hired to minimize staffing costs while meeting customer requirements related to their wait time prior to service.

Staffing costs are calculated based on the number of employees, their turnover rate, and the cost to train each type of employee. In this example, we can choose from three levels of employees. Those at the highest level, level 3, are more expensive in terms of training costs and salaries. However, they have a lower turnover rate and a quicker mean service time.

A threshold time is defined by the model user. The model calculates based on the queues how many of the customers have to wait for some time that exceeds the threshold time. This might be important if the business has placed some type of guarantee on the wait time for customers that results in a financial penalty to the business or if customers are likely to take their business elsewhere if the wait time exceeds this threshold value.

- From Crystal Ball examples

# Crystal Ball - MONTE CARLO SIMULATIONS EXAMPLE Workforce Planning with Queuing cont.

**Discussion**

The problem is to find the number of tellers and the level of each that will provide acceptable performance in terms of the customer wait time and minimize staffing costs. Several factors that are necessary to complete this calculation vary. In order to account for this variance, Crystal Ball assumptions are applied:

- The time between arrivals is characterized by an exponential distribution. The rate is found using a lookup function and a table. This allows us to more closely model reality, where the rate of arrivals is not constant throughout the day.
- The number of new employees is calculated using a binomial distribution in B7:D7 on the summary tab. The assumptions reference the corresponding turnover rate for each type of employee as the probability and the number of employees at that level as the number of trials.
- The time required to serve each of the customers is also variable. The service time is based on a normal distribution. The parameters of the distribution depend on the level of teller working in that queue.

- From Crystal Ball examples

# Crystal Ball - MONTE CARLO SIMULATIONS EXAMPLE
# Lean Speed & Six Sigma Quality

**Summary**

This financial-based model demonstrates how Lean Speed and Six Sigma Quality can be combined to uncover, measure, and reduce rework costs to address the "hidden factory" of defects that exists within an organization. While reducing “defects” (the target of Six Sigma) and reducing “lead time” (the target of Lean Principles) will independently offer some gains in cost savings, only by combining both techniques can you improve both speed and quality and achieve the lowest costs. Simulation is added to this model to incorporate and address the impact of variability on the Cost of Poor Quality and the Cost of Poor Process.

**Discussion**

Each time we produce defects or waste in a process, time, labor, capital equipment, overhead and material have to be used to detect, analyze and correct that defect or waste. This cycle of detection, analysis, and correction ties directly back to the three elements of customer value entitlement: delivering defect-free products and services (quality), on time (speed), and at the right price (low cost).

Consider one such company that is modeled here. This company has three main operations (processes) that interact with each other. In this model, Procurement is responsible for procurement, inspection and storage of raw materials. Manufacturing is responsible for manufacturing the parts of our product from the raw materials and inspecting those parts. Distribution is responsible for assembling, inspecting, packaging and shipping the finished product.

Defects in the process steps cause "hidden rework," which is corrected through additional production (build another unit rather than repair an existing unit). Defects that escape undetected and reach the customer are handled similarly, but with an additional expense for customer relations/PR. A lower Sigma Level results in higher numbers of "defects," and therefore higher production required to meet customer demand. Because Sigma Level is uncertain, we will express it as a range.

Process efficiencies and related variables and costs are also included in the simulation. When the simulation runs, the model performs a backward pass, determining required production in each process sufficient to compensate for "defects." Next, process efficiency is examined to determine total resource availability necessary to support the required production. After running a complete simulation, you can determine the effect of poor quality and the effect of poor process.

- From Crystal Ball examples