M8L3a. Build Simulation Model with Uncertain Variables

Slide #1

This section discusses simulating uncertain variables using the capital equipment investment case study.

It covers the construction of a simulation model, interpretation of the results, and how to leverage these insights in the decision-making process.

Through this case study, we aim to provide business decision makers with a robust framework for understanding and applying simulation analysis to effectively manage uncertainty and make informed decisions.

Slide #2

Simulation Example

Capital equipment investment simulation case

Description: As the chief operation officer a manufacturing company, you need to decide on the capital investment on additional machines and associated labor for the next year to meet growing market demand.

The three possible scenarios (likely, best case and worst cases) represent economic and market uncertainty.

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As the chief operating officer of a manufacturing firm, you're tasked with making pivotal capital investment decisions concerning new machinery and additional labor for the upcoming year amidst uncertain market conditions.

To navigate this uncertainty, projections are categorized into three potential scenarios: likely, best and worst-cases to encompass the economic and market volatilities that could impact your business choices.

Slide #3

Business Economic Model

Uncertain variables (forecast)	Likely case	Recession	Strong economy
Sales demand growth	6%	2%	8%
Unit price growth	2%	1%	4%
Material price growth	2%	1%	4%
Fixed cost price growth	2%	1%	4%

Demand, delivery and revenue	Current year	Next year (additional machine)	Next year (status quo)
Annual sales demand	700,000	741,698	741,698
Annual delivery	700,000	740,000	700,000
Unit price	$ 250.00	$ 257	$ 257
Annual revenue	**175,000,000**	**190,281,800**	**179,996,297**
Production capacity			
# of machines	70	74	70
Capacity per machine	10,000	10,000	10,000
Total capacity	700,000	740,000	700,000
Total production	700,000	740,000	700,000
Variable cost			
Variable cost per unit	$ 150.00	$ 153	$ 153
Total variable cost	**$ 105,000,000.00**	**$ 113,150,879**	**$ 107,034,615**
Fixed cost			
Machine and operating labor (per machine	$ 720,000.00	$ 732,708	$ 732,708
Total machine and operating labor cost	$ 50,400,000.00	$ 54,220,413	$ 51,289,579
Others	$ 4,000,000.00	$ 4,070,602	$ 4,142,449
Total fixed cost	**$ 54,400,000.00**	**$ 58,291,014**	**$ 55,432,029**
Total cost	159,400,000.00	$ 171,441,893	$ 162,466,643
Total profit	**15,600,000.00**	**18,839,907**	**17,529,654**

Decision and Impact	Additional machine #	Additional machine #
	4	0

Likely-case summary	4 additional machines
Investment (machine and operating labor)	$ 2,930,833
Profit change	$ 1,310,254
ROI	45%

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The business variables under these three scenarios are outlined in the table on the left, while the economic model is depicted on the right.

It's important to note that this economic model does not incorporate the what-if function as discussed in the scenario analysis section.

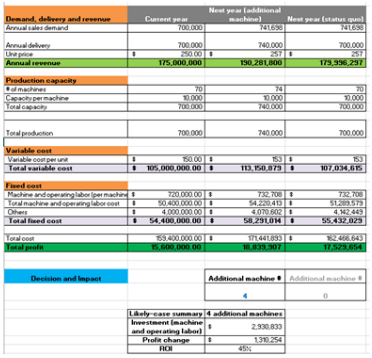
Slide #4

Business Economic Model

Likely Case if historical market trends prevail

Best and worst-case scenarios are the two extremes of risk and opportunities

Monte Carlo Method provides the scenarios between these extremes.



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4

In our previous scenario analysis, we leveraged Microsoft's what-if analysis to assess the impacts of these three distinct scenarios with the goal of aiding in informed decision-making.

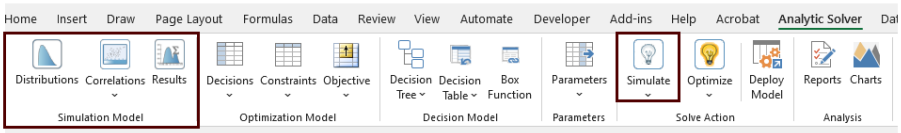
The likely case outcome projects the return on our investment should historical market trends continue.

However, we recognized a limitation in fully harnessing the insights from the analysis of the best-case and worst-case scenarios, which merely outline the boundaries of potential risks and opportunities.

Employing the Monte Carlo method allows us to simulate a vast array of scenarios from hundreds to thousands, spanning the spectrum between these two extremes, this approach enables the simulation model to generate a statistical distribution of the potential profits from our capital investment decisions, providing a more comprehensive view to guide our strategic planning.

Slide #5

Analytic Solver Simulation Model



Define simulation model details (Distribution of input variables, simulation results and display of results)

Run simulation

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To illustrate the practical application of simulation in decision making, we've selected the Excel add-in software, Analytic Solver, as our tool of choice.

Our focus will be on how to integrate simulation functionalities into the economic model for capital investments to bolster the decision-making process through enhanced data analytics rather than delving into the specifics of the simulation software tools themselves.

It's worth noting that there are several other simulation tools available on the market suited for various real-world applications.

Upon opening the Solver add-in, you'll find the Simulation Model section, which includes options for setting up your simulation, ranging from the distribution of input variables and outcome variables to the display of simulation results.

The simulation icon runs the constructed model.

Slide #6

Example #1: Simulate Uncertain Business Variables

Uncertain variables (forecast)	Likely case	Recession	Strong economy
Sales demand growth	6%	2%	8%
Unit price growth	2%	1%	4%
Material price growth	2%	1%	4%
Fixed cost price growth	2%	1%	4%

The initial step involves assigning distributions to the four input variables.

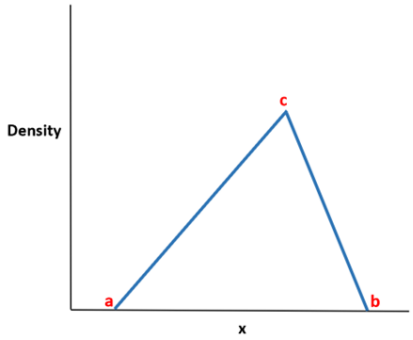
Given that each variable is described by three data points, a pragmatic choice is the triangle distribution function.

Slide #7

Triangle Distribution

Distribution function

$$P_x(x)=\begin{cases} 0 & for \quad x < a \\ \frac{2(x-a)}{(b-a)(c-a)} & for \quad a \le x < c \\ \frac{2}{b-a} & for \quad x = c \\ \frac{2(b-x)}{(b-a)(b-c)} & for \quad c < x \le b \\ 0 & for \quad b < x \end{cases}$$



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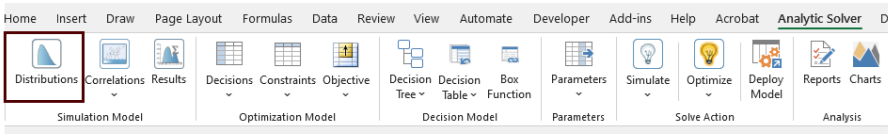
This function is graphically represented by a triangle simplifying variable analysis by concentrating on three pivotal points minimum most likely and maximum values.

It's piecewise mathematical representation places greater emphasis on the most probable outcome rendering it an effective predictive tool.

For more complex analyses with additional data, other distribution functions, such as normal or lognormal, may be applied.

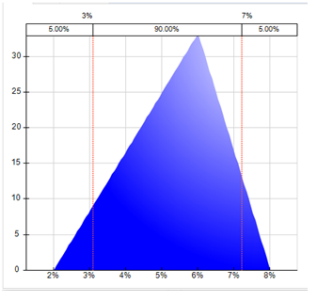
Slide #8

Define Distribution Functions of Uncertain Variables



Forecast of uncertain variables	Simulation variables
Sales demand growth	6%
Unit price growth	3%
Material price growth	2%
Fixed cost price growth	2%

Recession	Strong economy	Likely case
2%	8%	6%
1%	4%	2%
1%	4%	2%
1%	4%	2%

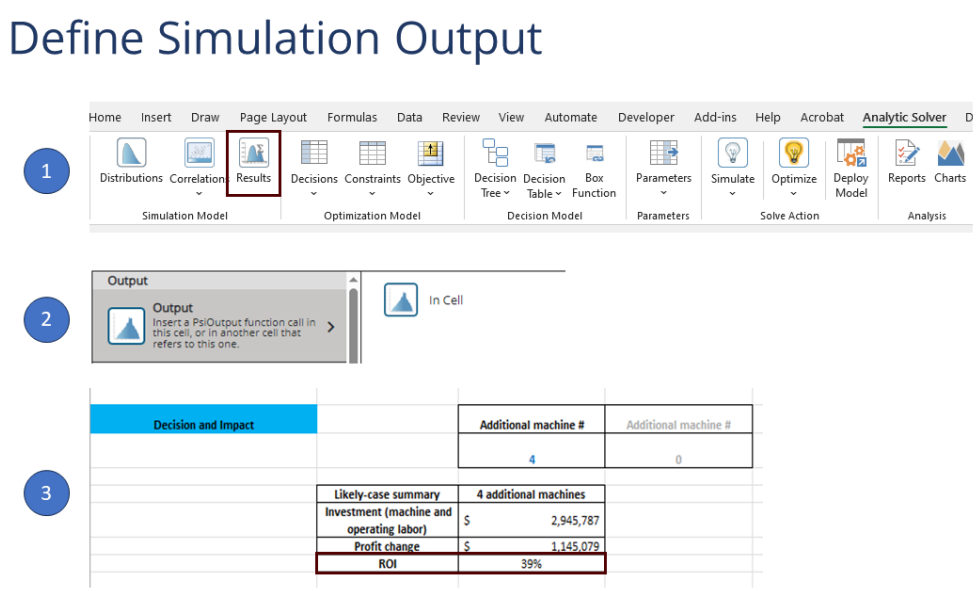


Triangle distribution of sales demand growth (2%, 6% and 8%)

Using the distribution button, we establish a continuous distribution function for each of the four input variables, sales demand growth, unit price growth, material price growth and fixed cost growth, specifying their minimum likely and maximum values.

An example of the triangle distribution graph for sales demand growth is presented alongside.

Slide #9



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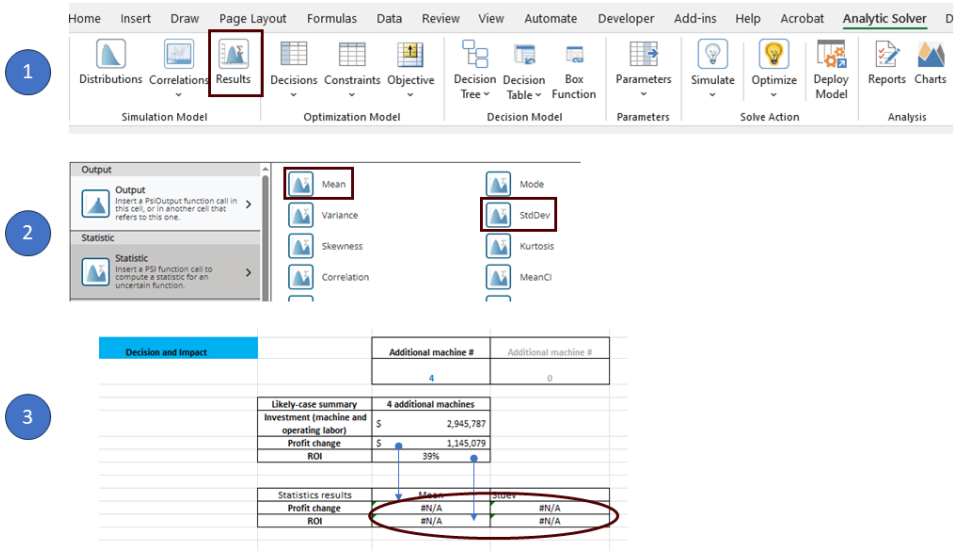
Next, through the output menu under the results icon, we identify the outcome variables, namely incremental profit and return on investment.

Slide #10

Define Display of Simulation Results



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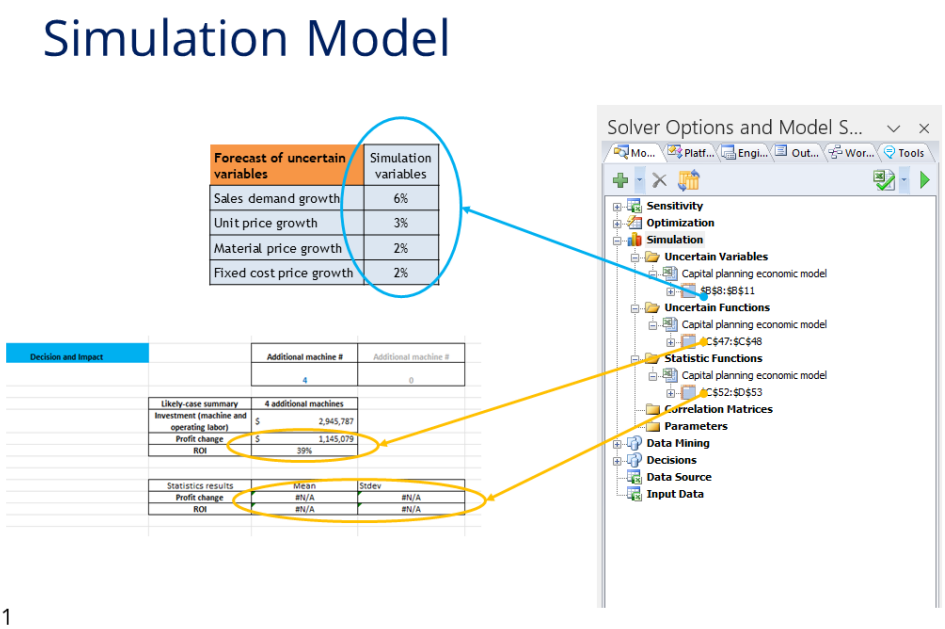
Moreover, the statistics menu allows us to display the statistical analysis results of the simulation.

In this case, we opted to display the mean and standard deviation for profit and ROI within the model.

Slide #11



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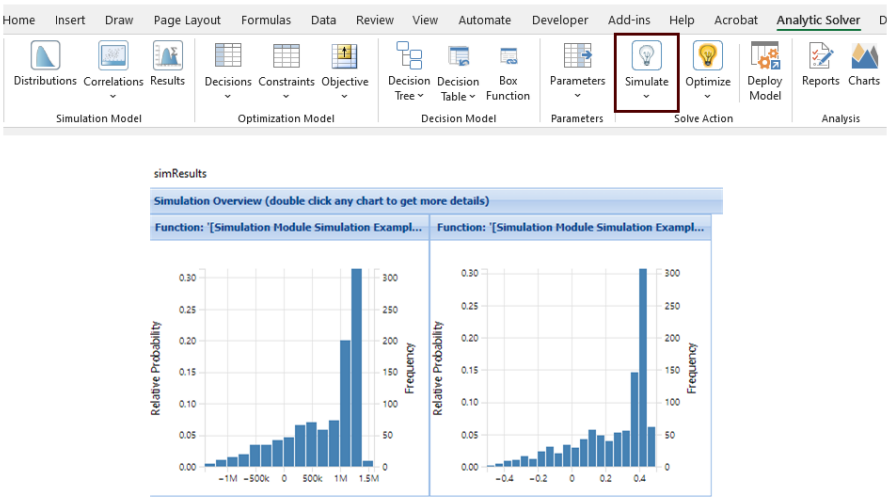
The solver model window offers a summary of the simulation model parameters for review.

Slide #12

Run Simulation



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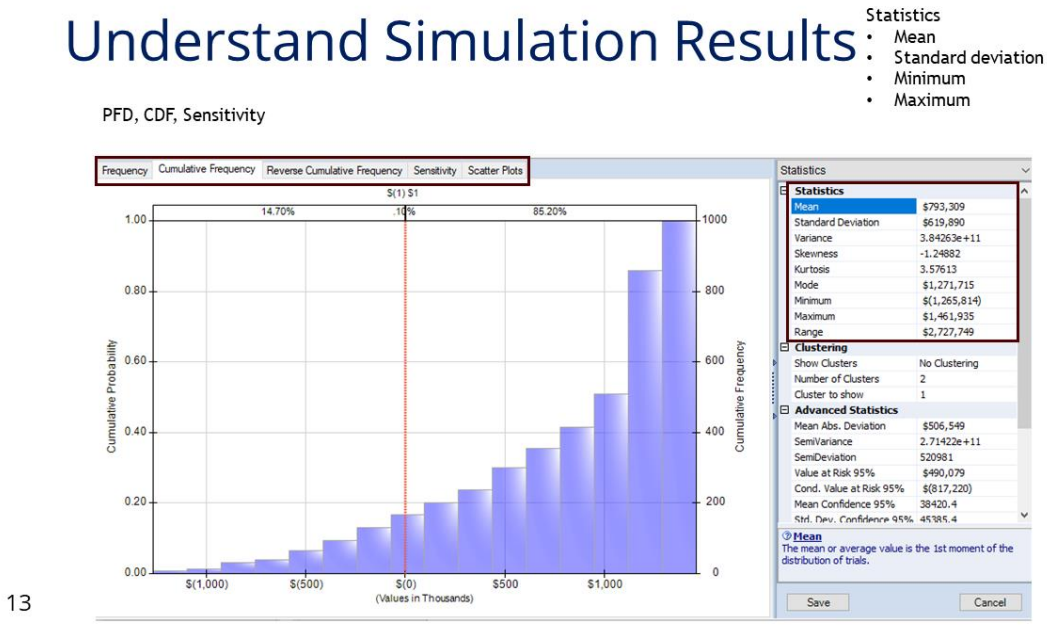
Once the model variables and results displays are configured, we run the simulation with 1,000 trials.

Solver performs the economic evaluation 1,000 times, applying random values to the input variables based on their triangle distribution function.

The resulting probability versus value for each designated outcome variable, profit and return on investment, is then illustrated in a bar chart.

The tutorial video for the simulation model construction, as well as results visualization and interpretation, is located after the lecture.

Slide #13



Understanding the insights from our simulation model is crucial for making informed decisions.

Solver provides a suite of visualizations including several key graphs alongside important statistical data.

For instance, consider the projected impact of investing in four additional machines.

The average expected profit stands at 0.79 million dollars with a variability, standard deviation, of 0.619 million dollars.

Remarkably, the most probable outcome points to a higher gain of 1.3 million dollars.

However, the range of possible profits is broad, highlighting the investment's intrinsic risk and potential.

Slide #14

Understand Simulation Results: Visualization

- **Frequency** (Probability density) shows the likelihood (of a variable achieving a specific value.
- **Cumulative frequency** (Cumulative distribution) demonstrates how values align with their percentile ranking in a distribution. It plots the probability of a random variable being less than (or, for the reverse cumulative, more than) a specific value.
- **Sensitivity analysis** determines how variations in input values impact the model's output, highlighting which inputs have significant effects on the outcomes.

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Key graphs include frequency, cumulative frequency, and sensitivity analysis.

Frequency shows the likelihood of a variable achieving a specific value.

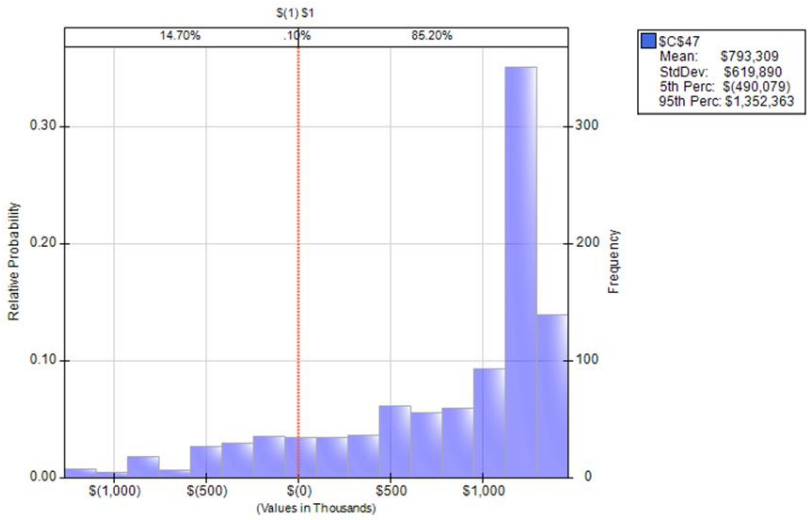
Cumulative frequency, cumulative distribution, demonstrates how values align with their percentile ranking in a distribution.

It plots the probability of a random variable being less than, or for the reverse cumulative, more than a specific value.

Sensitivity analysis determines how variations in input values impact the model's output, highlighting which inputs have significant effects on the outcomes.

Slide #15

Understand Simulation Results - Frequency



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To communicate the simulation results effectively to business decision makers, ensuring clarity and neutrality, or intentional bias for strategic emphasis in the presentation is crucial.

Here's a refined and persuasive interpretation of the insights from the uncertainty simulation.

The concept of frequency illustrates the likelihood, plotted on the y-axis, that a variable will reach a specific value, indicated on the x-axis.

Each bar's height reflects the probability density at that value, with the entire area beneath the curve adding up to 1, representing the full spectrum of potential outcomes.

The frequency analysis particularly reveals a 5% chance of incurring losses up to $490,000 and a corresponding 5% probability of realizing profits above 1.35 million dollars.

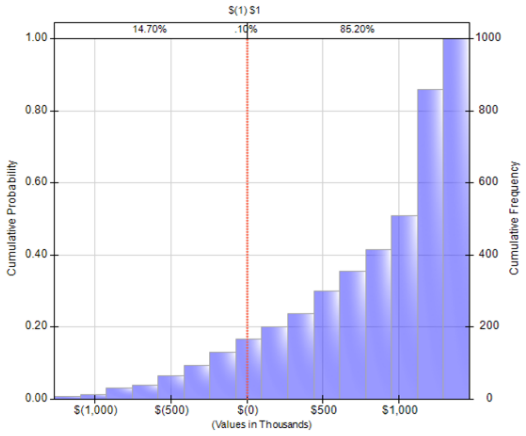
This equates to a 90% confidence interval for the projected profitability of this investment, ranging from a $490,000 loss to a 1.35 million dollar gain.

Moreover, the calculated average profit stands at $790,000, which is below the 1.3 million profit anticipated in the most probable scenario.

This discrepancy stems from the extensive variability in profit across different market conditions, indicating that the business should brace for significant profit fluctuations.

Slide #16

Understand Simulation Results: CDF



- 17% of probability that the investment of 4 additional machines will lead to a net loss.
- 83% of probability that the investment will generate positive net income.

Questions: How will you FRAME the statement to facilitate unbiased judgement?

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Delving into the cumulative frequency analysis provides another crucial insight.

Cumulative frequency or cumulative distribution demonstrates how values align with their percentile ranking in a distribution.

It plots the probability of a random variable being less than or for the reverse cumulative more than a specific value.

The chart begins at 0 and increases to 1, representing cumulative probability across the range of possible values.

This chart simplifies the identification of outcome intervals at various confidence levels.

For instance, there's a 17% likelihood that the investment might not yield a return, thereby incurring a loss.

Conversely, this implies an 83 % chance of realizing positive net gains from this venture.

When considering how to frame these insights to support unbiased or consciously biased judgment, it's essential to focus on the decision's context and the stakeholder's objectives.

For an unbiased presentation, emphasize the dual nature of the outcome, presenting both the potential for significant returns and the risk of losses in equal measure.

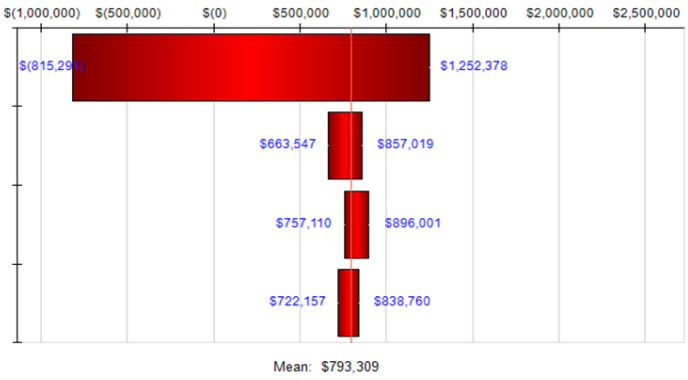
If a biased framing is strategically beneficial, you might choose to highlight the strong probability, 83%, of achieving positive returns to foster confidence while not omitting the risks involved.

This balanced approach ensures decision makers are fully informed and directs them towards a perspective aligned with the strategic direction or risk appetite of the organization.

Slide #17

Understand Simulation Results: Sensitivity

Sensitivity analysis measures how susceptible the output of a model is to alterations in the value of its inputs.



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Sensitivity analysis plays a crucial role in determining how changes in input values affect the outcomes of a business decision, making it invaluable for identifying the most impactful business variables on its performance.

This process aids in pinpointing which factors you should monitor closely to optimize your business's profitability.

For example, our simulation analysis identifies sales demand as a critical determinant in the success of capital equipment investments.

Slide #18

Sensitivity Analysis for Decision Making

Manage uncertainty

Reduce vulnerabilities

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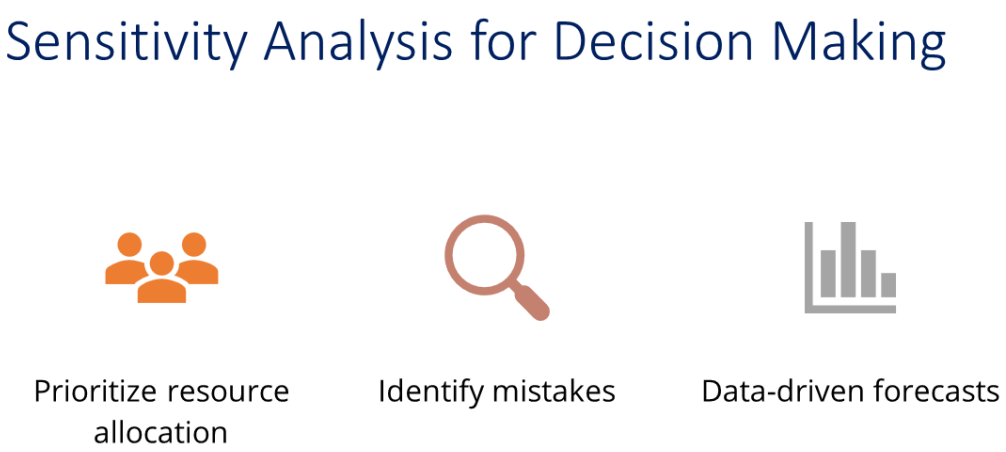
Sensitivity analysis enables decision makers to gain a detailed comprehension of the uncertain variables impacts on achieving business goals under various scenarios.

This in-depth insight into outcome drivers enables businesses to strategically prepare and plan.

The analysis also helps in identifying potential vulnerabilities, such as the sensitivity of profit margins to market demand fluctuations, allowing for the development of strategies to mitigate these risks.

Slide #19



Moreover, sensitivity analysis reveals areas where resource allocation can be optimized.

Recognizing the profound influence of market demand on profits, for example, guides management to allocate more resources toward marketing and sales efforts, aiming to capture a larger market share.

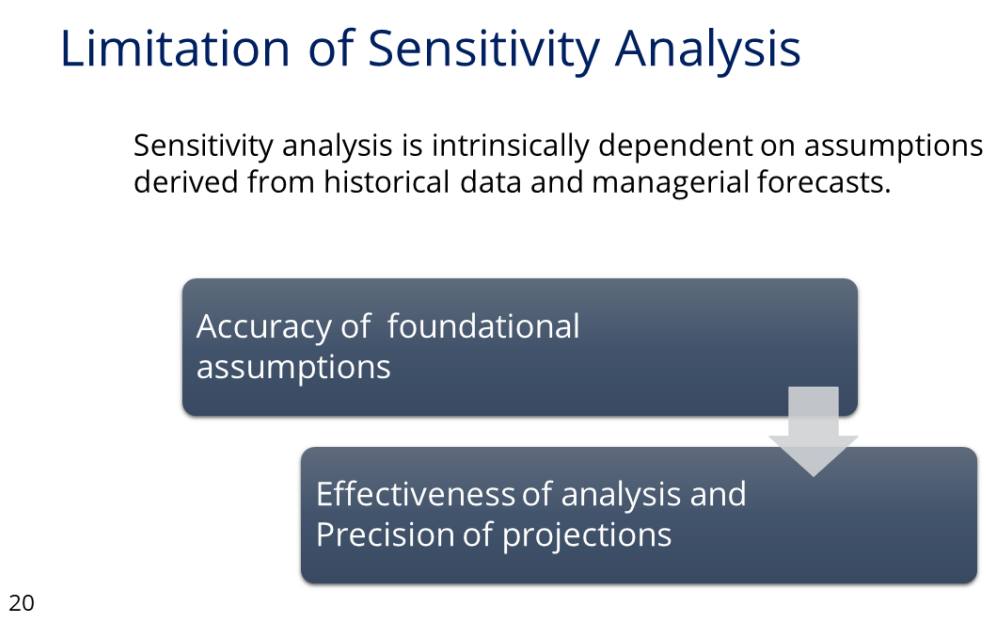
Additionally, this form of analysis can reveal errors in baseline assumptions, offering a chance to correct them for more accurate future projections.

It supports data-driven forecasting, facilitating transparent decision making on investments and serving as a fundamental tool for effective resource planning.

Addressing investor concerns regarding opportunities, uncertainties, and risks.

Sensitivity analysis demonstrates the potential impacts of different factors, thus backing more informed decision-making processes.

Slide #20



However, it's important to acknowledge the limitations of sensitivity analysis, notably its dependency on assumptions drawn from historical data and managerial forecasts.

The reliability of this analysis and the precision of its predictions hinge on the accuracy of these assumptions.

Inaccuracies, such as an overestimated decrease in raw material costs, leading to an unwarranted expansion of production capabilities, could adversely affect profit margins.

This emphasizes the need for accurate assumptions in sensitivity analysis, as errors can result in misjudgments, potentially compromising a company's competitive position.