

SENSITIVITY ANALYSIS

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DEFINITION

- A technique used to determine how different values of an independent variable will impact a particular dependent variable under a given set of assumptions. This technique is used within specific boundaries that will depend on one or more input variables, such as the effect that changes in interest rates will have on a bond's price.
- Sensitivity analysis is a way to predict the outcome of a decision if a situation turns out to be different compared to the key prediction(s).

YOU SHOULD PERFORM A SENSITIVITY ANALYSIS ANYTIME YOU

- Create A Model
- Write A Set Of Requirements
- Design A System
- Make A Decision
- Do A Tradeoff Study
- Originate A Risk Analysis
- Want To Discover The Cost Drivers

WHY SENSITIVITY ANALYSIS

- **Uncertainty** in various parameters used in Simulation Models – Feedback loops, Probability Distributions etc.
- Values of these parameters cannot be **estimated precisely** due to data availability or time constraints.
- **Less Reliable** Models: tested for their sensitivity to the changes in model components.
- Components, to which simulation results are sensitive, **need more attention** than other parts of the model.
- Parameter sensitivity of the model can be **compared** with the information from real system.

HISTORY: THE EARLIEST SENSITIVITY ANALYSES

- The genetics studies on the pea by Gregor Mendel, 1865.
- The statistics studies on the Irish hops crops by Gosset (reported under the pseudonym Student), ca 1890.

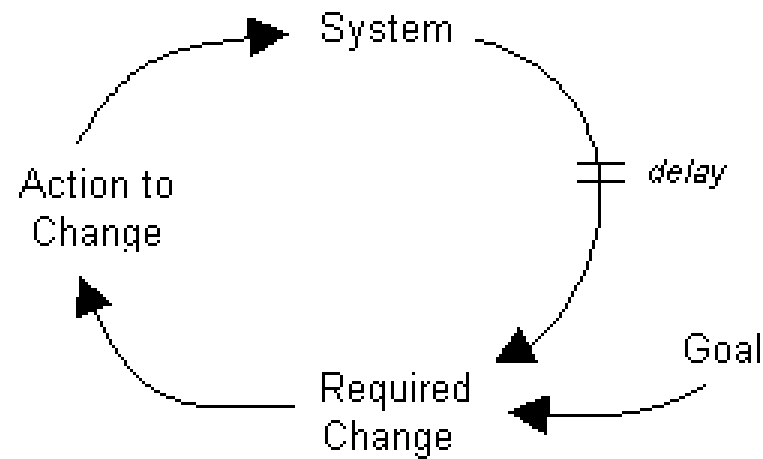
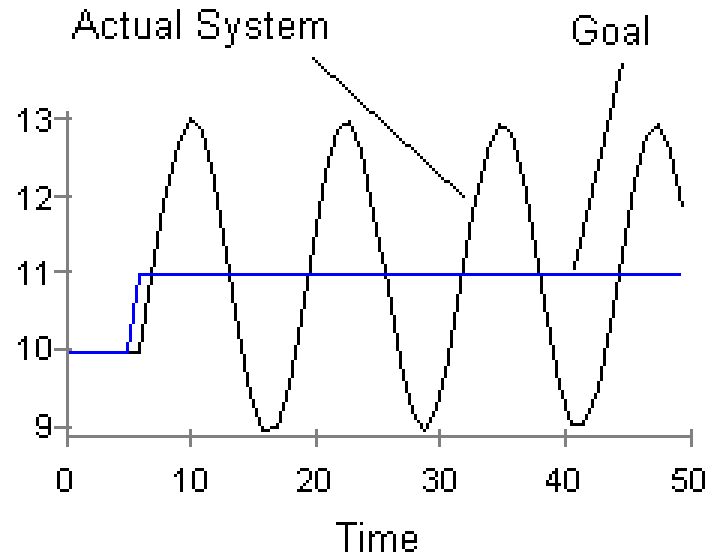


SYSTEM DYNAMICS MODEL

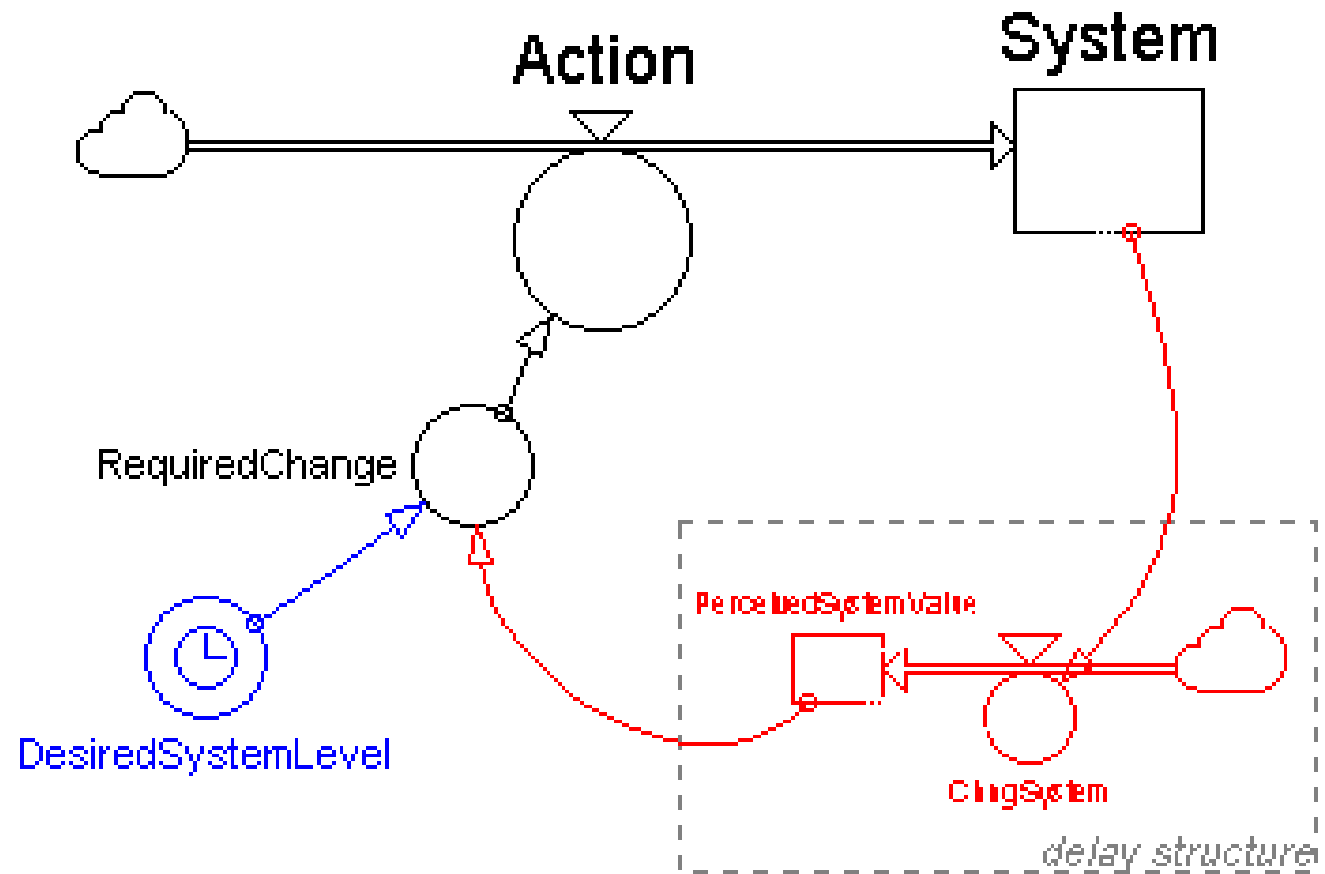
- The problematic behavior is tried to be explained by **system structure**.
- The **behavior pattern** of the system is the main interest of analysts rather than the specific values of the variables.
- Therefore, a **behavior-pattern-oriented approach** should be applied to sensitivity analysis
- It is **difficult** to analyze oscillations with **correlation based statistical methods** using the values of model variables, hence this approach is more significant

SYSTEM OSCILLATION

- System oscillation is the characteristic symptom of negative feedback structures in which the information used to **take goal-seeking action** is delayed



SYSTEM OSCILLATION



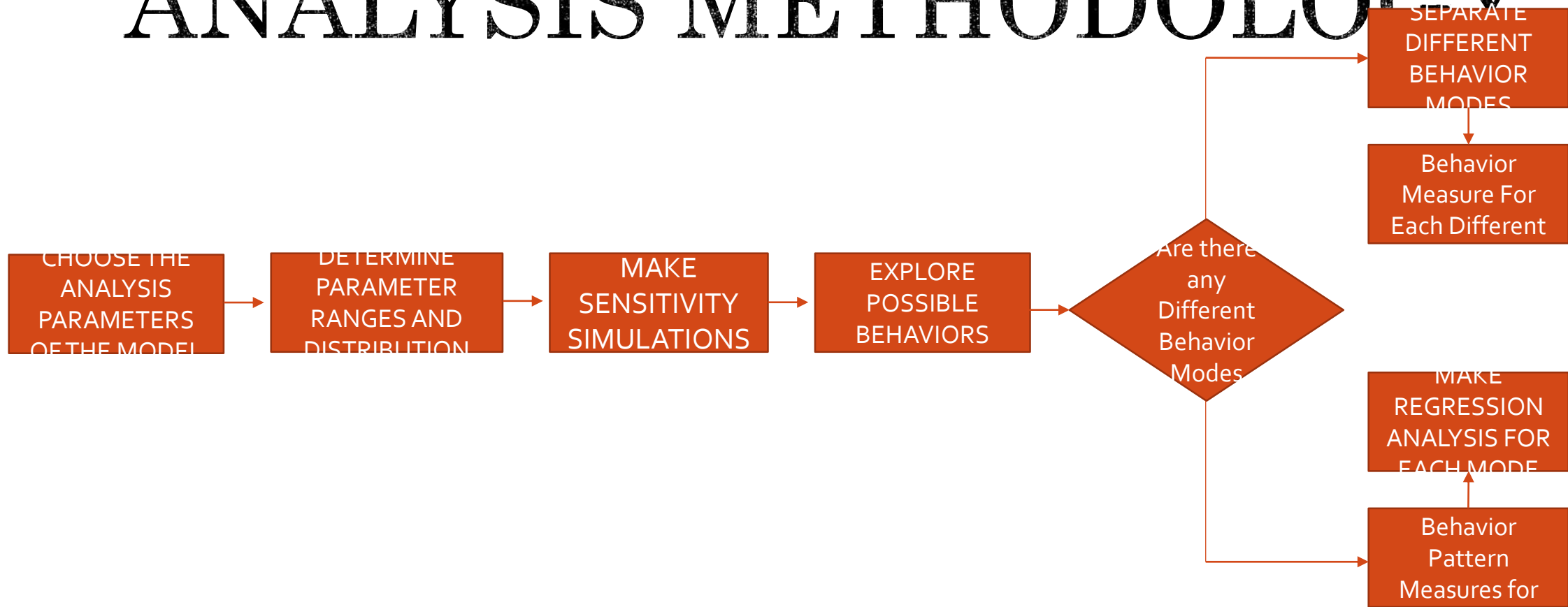
SENSITIVITY ANALYSIS IN LITERATURE

- In the study conducted by **Ford (1990)**, sensitivity of results are measured by partial correlation coefficients which indicate the **strength of linear relationship between two variables** after the effects of other variables are removed
- **Ford and Flynn (2005)** propose **Pearson correlation coefficients** instead of the partial ones for simpler sensitivity analysis procedure. This method is named as screening
- **Sterman (2000)** proposes that **numerical sensitivity** can be used for simulation models which work with great numerical precision such as models in physics or light simulators.
- **Policy sensitivity** is designed as the changes in the optimal policy when parameters values change (**Moxnes, 2005; Sterman, 2000**).

BEHAVIOR PATTERN SENSITIVITY

- Behavior measures are the subject matter of system dynamics studies in which the **problematic behavior is analyzed with respect to its structure.**
- For instance a population in an isolated area, which follows a boom and bust behavior, can be explained by **depleting resources and vanishing birth rate.**
- Sensitivity of the behavior to the model parameters can be analyzed by using peak or **equilibrium level of the behavior pattern.**
- Behavior pattern sensitivity aims to **explore the effect of varying model inputs on the specific behavior measures.**

BEHAVIOR SENSITIVITY ANALYSIS METHODOLOGY



SENSITIVITY ANALYSIS METHODS

- **Correlation & Screening Method**
 - Ford and Flynn (2005) suggest **Pearson correlation** in order to conduct quick sensitivity analysis, called screening.
 - In this method, correlation coefficients between the output and each parameter are **calculated and plotted against simulation time**
 - Parameters that have **high correlation with output variable** are concluded to be the **high sensitivity ones**
- **Regression Method**
 - Another convenient method assuming **linear relationship** between variables is regression.
 - In this method, an equation that minimizes the sum of squares of residual terms is calculated by using **ordinary least squares algorithm** (Draper and Smith, 1998).
 - When a **nonlinear relationship** is detected at the diagnosis of regression model, one can utilize **transformation on either dependent or independent variables**.

SENSITIVITY ANALYSIS METHODS (2)

- **Statistical Analysis (ANOVA) of Clusters in Scatter Plots**
 - Another efficient way of dealing with nonlinearity between system output and parameters is using statistical analysis of clusters in which **output variable y is plotted against each parameter x_j and this plot is subject to statistical analysis after it is divided into several clusters** (Kleijnen and Helton, 1999a).
 - This method is a more general way of one-variate sensitivity analysis since it does not have the linearity assumption between dependent and independent variables, i.e. this is a **statistical model independent method**" (Saltelli et al., 2000).
 - The scatter plot for each parameter is subject to statistical analysis in order to **detect any non-random pattern**.

SENSITIVITY ANALYSIS OF A BASIC OSCILLATION SUPPLY CHAIN MODEL

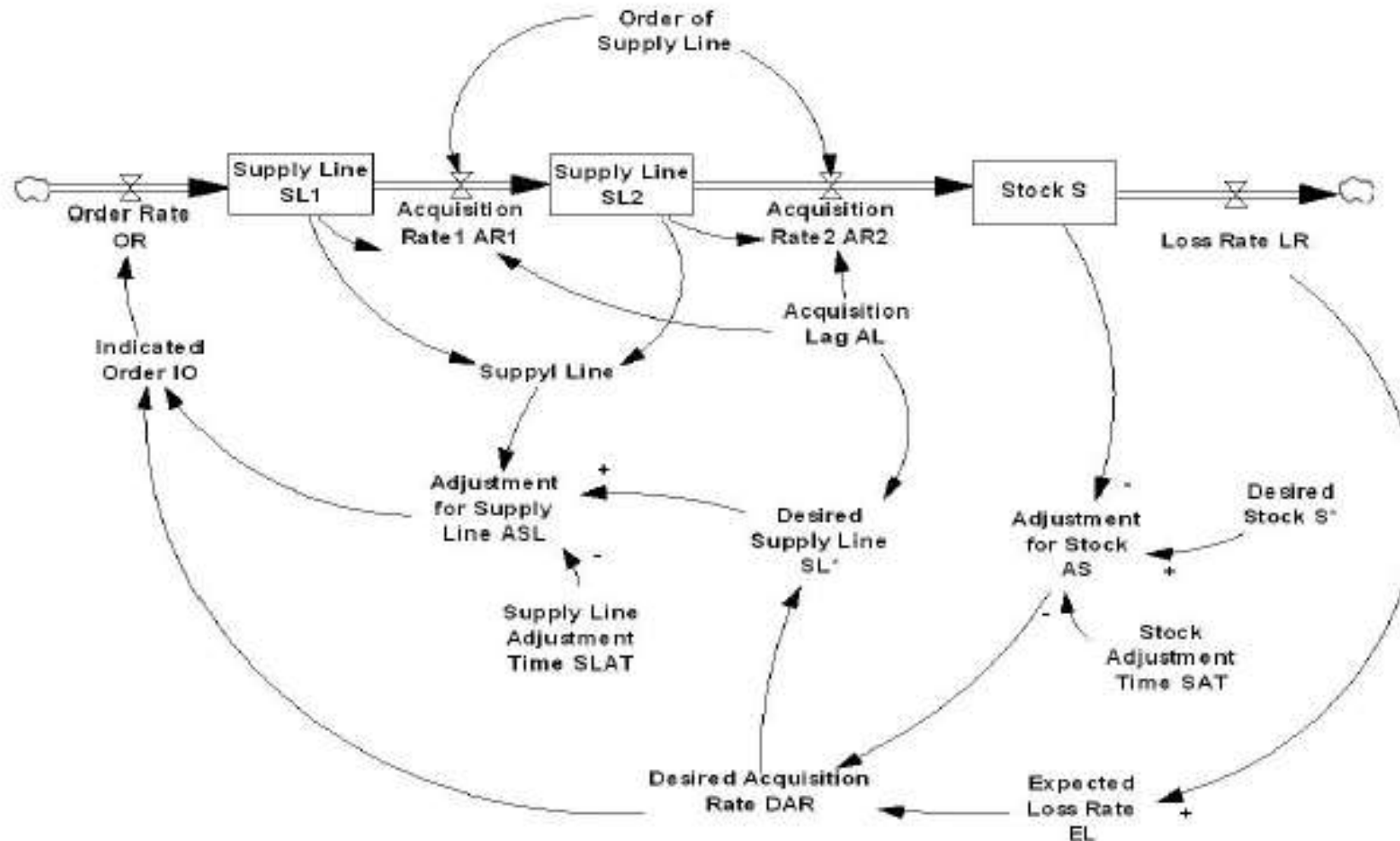


Figure: Stock Flow Structure of Simple Supply Line Model by Sterman (2000)

SENSITIVITY ANALYSIS OF A BASIC OSCILLATION SUPPLY CHAIN MODEL

- Supply chains are good examples of **material delay formulations** that are rigorously discussed in system dynamics literature.
- Supply chains consist of a stock and flow structure for the **acquisition, storage and conversion** of inputs into outputs and the decision rules governing these flows
- Include negative feedback loops that create corrective action once **discrepancy arises** between the stock and its desired level
- The transformation process in each supply chain takes some amount of time, i.e. there is a **time delay** in every supply chain structure.
- Interaction between **negative feedback loops and the time lag** may yield oscillations

PATTERN SENSITIVITY ANALYSIS OF OSCILLATION OF SIMPLE SUPPLY LINE

MODEL

- Oscillations are **cyclic behavior patterns** which are difficult to analyze with standard statistical techniques, such as screening.
- So, sensitivity analysis of oscillatory models should focus on the pattern measures of these behavior modes
- Common measures of an oscillatory pattern are **period, first amplitude and amplitude slope**.
- Period of an oscillation is **amount of time** between two successive peaks or troughs.
- This pattern measure indicates **how much** the system oscillates under certain circumstances.
- One of the critical steps in pattern sensitivity analysis procedure is the estimation of **pattern measures for each simulation run**.

SENSITIVITY ANALYSIS OF OSCILLATION PERIOD

- In this thesis, periods are estimated by **autocorrelation function in BTSII** which is a validation tool for behavior pattern tests of system dynamics models.
- According to the results of regression analysis, **stock adjustment time** is the most important parameter of the model.
- The second important parameter is **acquisition lag** which is the average time lag in supply line. Increasing values of this parameter yields longer-period oscillatory systems.

Table 1. Parameter Distributions of Simple Supply Line Model

Parameter Name	Actual Val	Min Value	Max Value	Distribution
Stock Adjust. Time (SAT)	2.5	2	3	Uniform
Supply Line Adjust. Time (SLAT)	3.75	3	4.5	Uniform
Acquisition Lag (AL)	11	8.8	13.2	Uniform

Table 2. Regression Results for Oscillation Period of Simple Supply Line Model

Coefficients					
Model	Regression Coefficients			t value	Sig.
	beta (β)	Std. Error	Std. Coef (b)		
(Constant)	.199	.339		.589	.557
StockAdjst	6.899	.078	.683	87.944	.000
AcqLag	1.510	.018	.657	84.671	.000
SupLineAdjst	2.026	.052	.301	38.722	.000

Table 3. Summary Statistics of Regression Model for Period

Model Summary		
R Square	Adjusted R Square	Std. Error of the Estimate
.988	.988	.320

Table 4. Results of ANOVA Test of Clusters for Period

ANOVA Results for Period			
Ranking	Parameter Name	F Value	Significance
1	AcqLag	38.874446	0
2	StockAdjst	36.302405	0
3	SupLineAdjst	5.511978	0.00031754

REFERENCES

- A methodology for statistical sensitivity analysis of system dynamics models by Mustafa Hekimoglu

(www.Ie.Boun.Edu.Tr/labs/sesdyn/publications/theses/ms_hekimoglu.Pdf)