# Modeling Judgment and Decision Making Process Using System Dynamics

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**Abstract**

We argue that System Dynamics modeling process, during its conceptualization to the model evaluation and to policy experimentation phases, removes the criticisms to rationality view of Judgment and Decision Making (JDM) and implicitly considers the psychological factors. The criticisms of rational theory of JDM are basically due to the limitation of cognitive ability of the decision maker to perceive the complexity of the context, to the imprecise and imperfect idea about the factors influencing, to the using of simplified decision and choice selection rules, and to the personality of the decision makers, i.e. developing perception, getting biased, and managing risks. We argue that the philosophical origin and prescribed modeling processes of System Dynamics takes care of the limitations to rational decision making processes and captures the effect of psychological factors in the model. We have illustrated few System Dynamics models of how the *Decision Traps,* often described by the integrated JDM literature, are formed and how are the behavior of decision maker's decisions. We conclude that System Dynamics models can be developed to explain JDM situations which can easily explain the economists' modeling approach and experimental approach of behavioral scientists towards understanding JDM situations.

**Key Words**: Judgment and Decision Making, System Dynamics, Cognition, Emotions

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# 1. Introduction

In the past decades, both the economists and psychologists have fought themselves to prove against each other and win over their own theories on JDM. Economists are on the opinion that the decision makers as an economic "agents" always try to take a rational choice as the "decision" in order to maximize his *utility* (*rewards compared to sacrifices*) and have proposed various models to arrive at such decisions. Conversely, following experimental approaches the psychologists use to show how different *"choices"* are made by the human beings in the same decision making situations (Sterman, 1987). Though this debate has been old, in the recent past both the scientists have worked with collaborations and have explored the complementary relationship of both economics and psychology in the JDM situations.

In this paper, we made an attempt to explicitly define and study the role of psychological factors in Judgment and Decision Making (JDM) and to integrate them into system dynamics modeling process. In a business setting, either one individual decision maker or a group of decision makers make decisions. In the case of one individual decision maker, i.e. the manager or the CEO, who is responsible for most of the decisions related to business and organization. In the context of a multiple decision makers, like a team or a board, many people make decisions through group meeting(s). The effect of psychological factors in both the contexts are different. For example, in the case of the multiple decision makers, both positive and negative effects of psychological variables can assumed to nullify and pure rational economic decisions rules could be assumed. Though there would be some situations where one cannot ignore the effect of psychological factors completely, particularly when all the decision makers are inclined to either positive or negative side. However, in a situation where only one central decision maker is there, the model needs to explicitly capture the effect of psychological factors into the decision making rules and decision making. We conclude that many of the psychological characteristics of human decisions are inherently factored into system dynamics modeling due to its nature of its philosophical origin. Nevertheless, the modeler during model evaluation process could also explicitly test the effect of such psychological factors on the model behavior and could improvise the model structure accordingly.

# 2. Judgment and Decision Making (JDM) Process

System Dynamics as a discipline, grounded over the notion of *structure leading to behavior,* could act as a methodology to blend the *modeling* aspects of Economists and *experimental* approach of Psychologists, to aid in JDM process.

## 2.1. Psychological Factors and Economic Decisions

The decision making process has three basic constituents: *decision situation*, the *decision maker,* and the *decision process* (Wang & Ruhe, 2007). Rational economic decision making involves identifying a set of alternatives (act, course of action, or strategy) and making a *choice* from such set. The objective of the decision maker through a choice is to get some *reward* and making some *sacrifices.* Hence, every alternate *choice* would have a set of a *reward* and a *sacrifice.* A *rational* decision maker makes a choice in such a way so as to maximize the *reward* and to *minimize* the *sacrifices.* But the truth is, cognitive process in human mind is far from *rationality* assumption; in fact the thinking of human being is influenced by a number pf potential *biases* and *errors* (Baron, 1998), hence, the process of identification of alternatives and making a "*best*" choice are not easy. Identification requires a complete understanding of the system and selection of choice involves calculation of rewards and sacrifices and making a trade-off. Both the process involves use of assumptions, relying on imprecise and incomplete data, and simplified calculation. Hence, the assumed degree of rationality of the decision making process is diluted. As human being is involved in the process, the psychological factors related to human behavior also play critical role in decision making. Before discussing the role of psychological factors in decision making process, we present below in ***Figure 1*** a pictorial representation of rational economic decision making process.

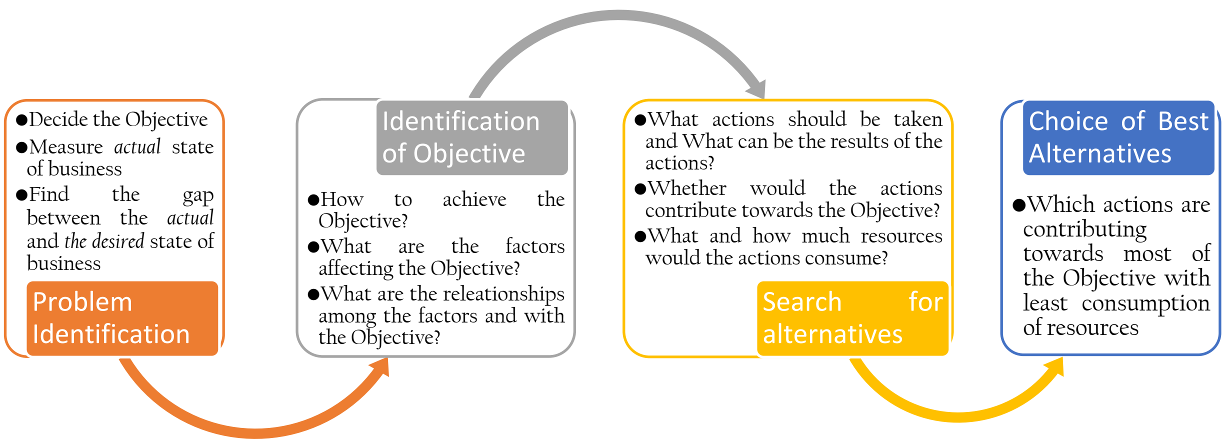



**Figure 1: Step-by-Step Decision Making Process**

As there exists a step-by-step approach to decision making process, the scientists have developed and suggested various models in different contexts to help the decision makers to arrive at the decisions. The models are basically abstracted representation of the reality, i.e. the context, the objective, the factors, the relationships amongst the factors, the search procedure for alternatives, and the choice of best alternatives. As there is a choice involved in the decision making in order to best trade-off between the *reward* and the *sacrifice*, it fits into a kind of optimization model which is shown in **Figure 2**.

| | | |
|---|---|---|
| **Step 1** | **Problem Identification** | $\boldsymbol{Z_0 < Z_{desired}}$<br>$\boldsymbol{Z_0: Actual\ state\ of\ business\ at\ time\ zero}$ |
| **Step 2** | **Identification of Objective** | $Min\ Z = \lvert Z_{desired} - Z_0 \rvert \Rightarrow Max\ Z_{desired} = f(X_i)$ |
| **Step 3** | **Comprehensive Search for Alternatives** | $\{X_i\}, \quad \forall\ i = 1,\ 2,\ 3,\ \dots and\ X_i: Set\ of\ Alternatives$ |
| **Step 4** | **Objective Evaluation of Alternatives** | $Find\ X_i \mid Z_i > Z_0, \quad \forall\ i = 1,\ 2,\ 3,\ \dots$ |
| **Step 5** | **Selection of Alternatives most likely to achieve Objective** | $Select\ X_n \mid Z_n = max(Z_i), \quad \forall\ n \in \{i\}$ |

**Figure 2: Economic Decision Making Process in the form of an Optimization Problem**

The decision making process explained earlier is however criticized for containing lot of assumptions and having lack of precision. If we analyze the sequence of activities in the decision making process, we find that there is a human being or a group of human beings, who take important roles in the every step of decision making. For example, in the very first step, *deciding the objective*, different human being would have different objective. The objective set would vary from one group of people to another as well. Similarly, measuring and reporting the actual states of the business would also have human influences and so on. Therefore, when human is involved in the decision making process, the role of psychological factors in the decision making process cannot be ruled out.

In the past decades both psychology and economics literature emphasized their complementary role in human decision making. Economists have considered how both cognitive and emotional factors do affect decision making. Along with the PESTLE (Political-Economical-Social-Technological-Legal-Environmental) factors, cognitive and Emotional factors do also play a larger role in the decision making process. Hence, in a condition of *irrationality* or *bounded rationality* or *conditional rationality*, straightforward selection of optimal choice is not possible—rather an evolutionary approach to search for alternatives is advocated (Aumann, 1997).

For decades, the economists have developed various theories to explain how decisions are made. The decisions are centered on selecting an alternative out of many transitive ones such that the choice generates maximum subjective value or utility. The theory goes with an assumption that people behave *rationally* that means they always choose in such a way that the subjective value/utility is maximized and the choices are free from any kind of risk. However, it is hard to say that the measurement of utility is correct all the time, the choice set is complete, and the choices are free from intransitive patterns (Edwards, 1954) (De Bondt & Thaler, 1994). To deal with such intransitive property of choices the economists have developed stochastic decision making models, where the *rewards* and/or *sacrifices* are defined to *expected rewards* and *expected sacrifices* attached with some probabilities. The uncertainty is further captured using *Bayesian* based decision making process, where the decision maker quantifies trade-offs between various choices probabilities and costs that are attached with such choices. The Bayesian decision theory is included in Descriptive theory of decision making where the actual decision making process is captured unlike the rationality assumption in Normative theory. Based on the Descriptive theory, the decision is made based on the *prior* probabilities of the system events, evaluation *posterior* probability, and considering *risk.* We present below a conceptual model of decision making situation in **Figure 3.**

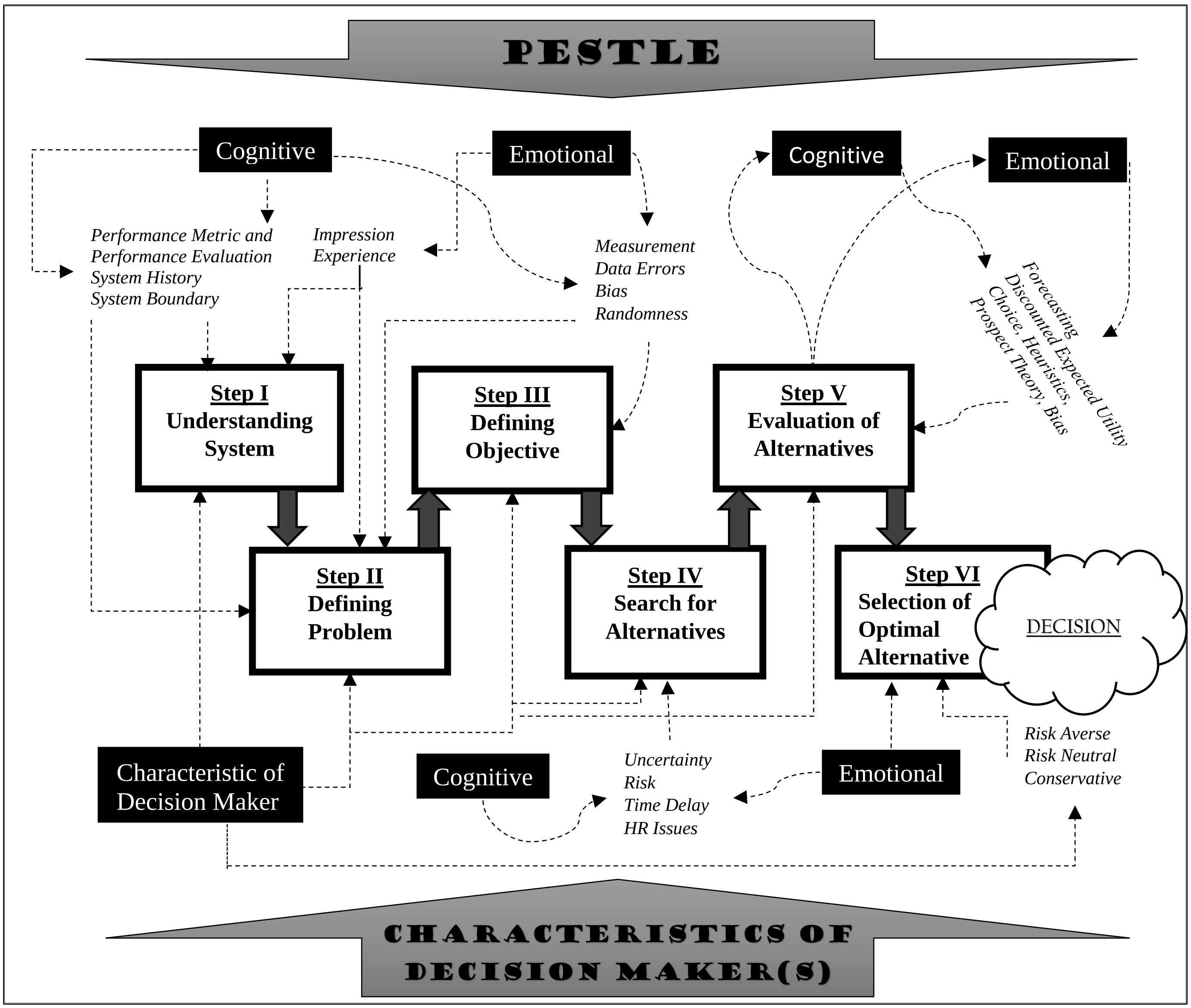



**Figure 3: Integrated Conceptual Model for Decision Making Process**

From a process point of view, the decision making process is considered to carry various decision rules. The decision rules are the guiding elements in the various steps of decision making process. The rules are classified and presented in **Table 1** (Svenson, 1979).

**Table 1: Classification of Decision Rules in the Various Steps of Decision Making Process** *(Svenson, 1979)*

| | **Non-commensurability** | **Commensurability** |
|---|---|---|
| **Ordinal Attractiveness** | • Dominance Rule<br>• Conjunctive Decision Rule | • Maximizing Number of Attributes with greater Attractiveness Rule<br>• Elimination by Least Attractive Aspect Rule<br>• Choice by Most Attractive Aspect Rule |
| **Ordinal Attractiveness and Lexicographic Order** | • Lexicographic Decision Rule<br>• Elimination by Aspects Rule | • Choice by Greatest Attractive Difference Rule |
| **Ordinal Attractiveness Difference and Lexicographic Order** | • Minimum Difference Lexicographic Rule | |
| **Interval Attractiveness (Utility)** | | • Addition of Utilities Rule<br>• Addition of Utility Difference Rule |
| **Ratio Attractiveness** | | • Subjective Expected Utility Model |

The decision rules presented in **Table 1** are used to make a *choice* out of the set of *alternatives.* The decision maker uses one or a set of attributes to evaluate alternatives based on their attractiveness or utilities. The decision rules are applied to a set of information gathered by the decision maker. The information may or may not be complete. Hence, the decision maker uses algebraic models to take a decision which are mostly based on surface description of the cognitive activity due to incomplete information. When the number of alternatives and attributes increase, the algebraic models are able to address smaller number of *aspects* of the problem. Hence, people use *heuristics* to simplify the "messy" complex problem into simple and understandable situation with visible *patterns.*

As the subjectivity of decision maker in perceiving the problem play a crucial role in decision making process, economists have explored the factors concerned with the perception process. Here comes the role of psychological factors. De Bondt and Thaler (1994) have described five major type of psychological factors related to decision making made in firms. They are: Overconfidence, Non-Bayesian forecasting, Loss Aversion-Framing-Mental Accounting, Fashions-and-Fads, and Regret-Responsibility-and-Prudence.

## 2.2. Role of Emotional Variables in Decision Making

*"Emotions"* are defined as a form of mental state varying from momentary reactions to long-lasting durable mood, are kind of subjective feelings characterized by complex coordination of physiological, hormonal, and expressive activity, are some evaluations of positive and negative associations with affective relationship *(Lerner J. S., Li, Valdesolo, & Kassam, 2015)*. Emotions do also effect on quality of relationships, sleep patterns, economic choices, political and social policy choices, creativity, and physical

and mental health *(Lerner J. S., Li, Valdesolo, & Kassam, 2015)*. Lerner et al. (2015) has illustrated eight major themes that describe the impact of emotions on decision making and finally proposed an integrated model of JDM. Tran (2004) has identified four classes of emotional variables: (1) Antagonostic EMotions—Envy, Disgust, Contempt, and Anger, (2) Achievement Emotions—Pride, Elation, Joy, and Satisfaction, (3) Approach Emotions—Relief, Hope, Interest, and Surprise, and (4) Resignation Emotions—Sadness, Fear, Shame, and Guilt. He has further classifed based on "*pleasantness*" and "*controllability*" basis as presented in **Figure 4**.

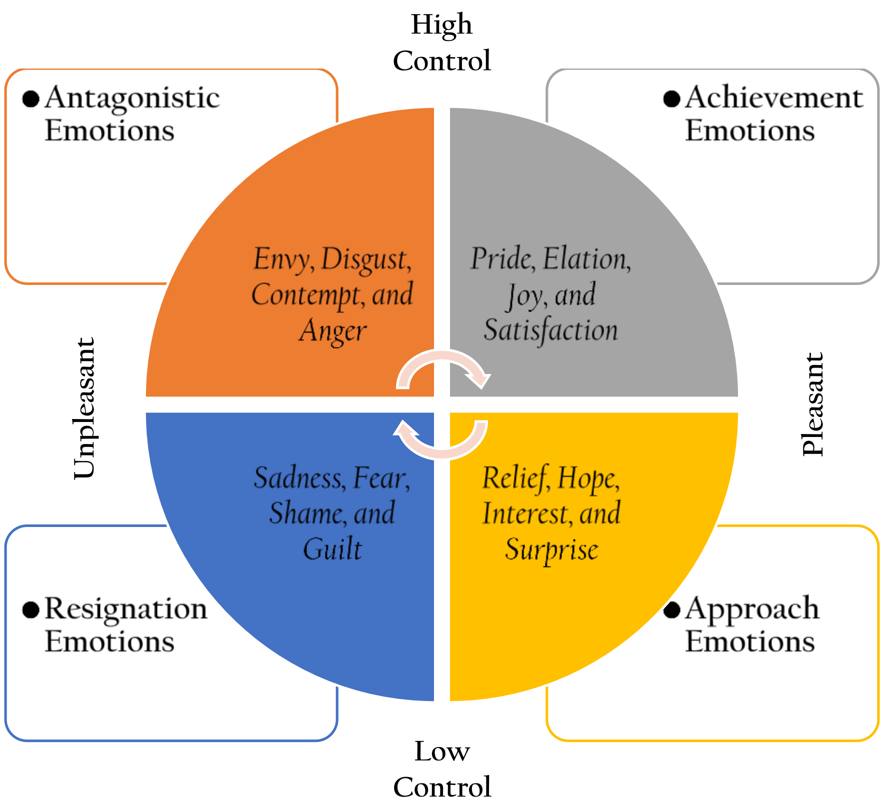



**Figure 4: Classification of Emotional Variables Influencing JDM** *(Tran, 2004)*

# 3. Discussions

## 3.1. System Dynamics: Blending the Economics and Psychology into Decision Making

Decision making is objective driven behavioral process within a set of alternatives. Decisions are not made continuously. There is always an implementation process after the decision is taken. However, sometimes, the implementation process is so long that we call it as a *static* decision. But, there is always a *delay* in between two consecutive decisions. Hence, decision making process is dynamic in a business context.

Starting from the genesis of System Dynamics, decision making situations are captured and ingrained into the models. Forrester (1958) in his *Industrial Dynamics* (Forrester, 1961), modeled the ordering *decisions* in a supply chain indicating how the supply orders fluctuate at the upstream supply chain if there is a small change in sales at the retail level. Similarly, the inclusion of other psychological varaibles in decision making process are also captured as presented in **Table 2**.

**Table 2: How Does System Dynamics Modeling Consider Limitations to Rational Decision Making Process?**

| # | Factors influencing rational decision making process | How does System Dynamics modeling captures the factors in decision making process |
|---|---|---|
| **1** | Systematic and Sequential Decisions | • Captured through dynamic simulation of the Stock-Flow model |
| **2** | Complexity of the Context | • Building a Structural Model ( Both Causal Loop and Stock-Flow models) through judiciously considering the boundary of the system<br>• The fluid boundary of the system is also evaluated and adjusted while testing the sensitivity of parameters |
| **3** | Delay in the Cause and Effect | • Captured through modeling Delay in the Stock-Flow model |
| **4** | Feedback: Cause→Effect→Cause | • System Dynamics is grounded on feedback theory |
| **5** | Heuristics<br>E.g. Anchoring and Adjustment | • The Cause-Effect relationships are based on the actual heuristics of the decision maker<br>E.g. Captured in the model through First Order Delay Stock-Management principle (Sterman, 1987) |
| **6** | Bias | • The biases of the decision rules are checked during model evaluation method |
| **7** | Errors in the data/Uncertainty in Data | • Captured in the model by defining the value of the variable as a Probability Distribution |
| **8** | Non-linearity | • Captured in the model through appropriate Table Functions or Look-Up Functions |
| 9 | Post-Decision Affect | • Captured by appropriately modifying the structure |
| 10 | Anticipated Affect | • Captured through using forecasting techniques in System Dynamics |
| **11** | Effect of PESTLE factors | • Captured during the model evaluation process while doing testing for sensitivity of parameters and structure verification |

In the illustrated integrated conceptual model for decision making (**Figure 3**), we have shown how both psychological and economic factors are affecting the decision making process along with the PESTLE factors. We discuss below how each of those factors are implicitly captured during System Dynamics modeling as summarized in **Table 2**.

1. As argued earlier, there is no discrete decision. The decisions are made in sequence. Hence, simulating the System Dynamics models over time is equivalent to repetitive decision making processes.

2. Perceiving the complexity of the *whole* picture of the context by the decision maker is criticized in the decision making process. System Dynamics starts with the philosophy of building a *structure* representing the system. Using Causal Loop Diagrams (CLD) and Stock-Flow Diagrams (SFD) the modeler captures the most of the factors of the system.
3. Most of the times in a business context, there are *Delays* between the Effects and Causes, which finally influences the outcome due to the Cause (an action or a decision). The rational decision making process finds its difficulty in perceiving and capturing those delays in the decision making process. However, the System Dynamics modeling very well captures those Delays with ease.
4. Feedbacks always exist in systems and System Dynamics is grounded on the feedback theory.
5. Heuristics are simplified rules that are assumed to have a simplified view of the decision rules and decision making process. In System Dynamics modeling, we can capture the rules as-it-is by exploring them through the interview with the decision maker. How does he make decision? What is his decision rule? What is his method of selection of choice? The heuristics used by the decision maker is captured through proper defining of cause-effect relationships in System Dynamics models.
6. Biases of decision maker can come from various sources. These biases create irrational decision processes and generate various kinds of Decision Traps. System Dynamics models could capture those biased elements of decision making process.
7. Information and data on variables used in decision making process obviously could carry uncertainty and errors. The threat of errors and uncertainty could be taken care of by converting the variable from a static value to a probability distribution. Stochastic models are more realistic and believed to generate expected values of the objective function.
8. The cause-effect relationships are not linear most of the time. Using Look Up/Table functions, non-linear relationships are captured in System Dynamics models.
9. The relationship between two consecutive decisions are bidirectional. Furthermore, according to Schwarz (2000), the emotion and decision making is also bidirectional. The negative or positive outcome of a decision maker affect the decision maker's feelings and change the emotional state of him, which in turn affects the next decision. This feedback relationship is presented through a causal structure in **Figure 5**. The System Dynamics models can ingrain the structure and use the feedback relationship between emotions and decision making.

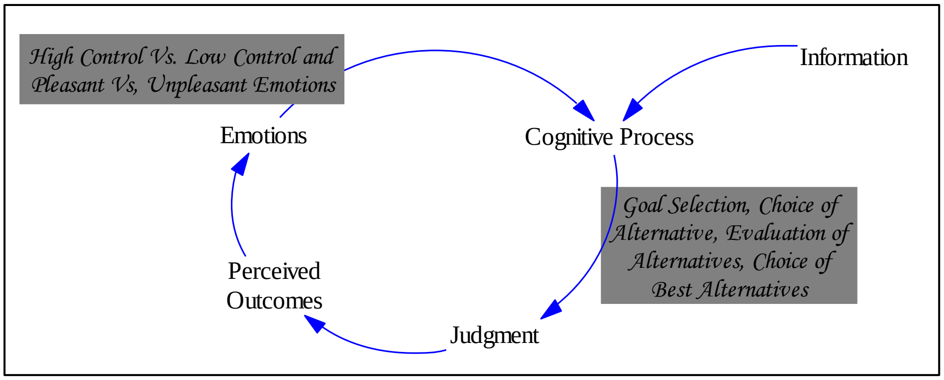



**Figure 5: Interaction of Emotions and Cognitive Process in Decision Making**

10. Decision makers always try to avoid likelihood of appearance of *unpleasant* emotions like *regret* or *disappointment* due to their decisions (Schwarz, 2000). Hence, the future likelihood of emotional state because of outcomes are perceived and used in decision making. For example, parents hesitate to vaccinate their child with a vaccine having possible fatal side effects. The vaccination may have two outcomes; first it may cause potential fatal damage due to side effects which is having a rare probability of occurrence and second it may prevent a death in future which is having higher probability than the side effect. The hesitation of the parents is because of the anticipated regret in a short-term is more intensive than the future (Ritov & Baron, 1990). In System Dynamics, this kind of decisions can be modeled using the forecasted variable of the emotions due to unpleasant outcomes in a short-term, with which the decision maker anticipates a *guilt*.
11. PESTLE factors in System Dynamics models are defined as exogenous variables. The sensitivity analysis of parameters under the Model Evaluation scheme of System Dynamics could capture the effect of change in PESTLE factors (Forrester & Senge, 1980).

## 3.2. Traps in Decision Making: Capturing through System Dynamics Models

Human makes decisions in the mind. As elaborated in the previous sections the decision making process is not straight forward. Hence, the decisions are always attached with a risk of being wrong. The decision could be a wrong or a bad decision due to the lack of clarity about the problem and its context, lack of availability of correct and precise data, limitation of human mind for cognitive processing leading to assumption of less-than-best heuristics, and role of emotional variables on the whole decision making process. And, finally the decision makers are entangled with *Decision Traps* (Hammond, Keeney, & Raiffa, 2006). We explain below some of the decision traps and unfolded the structure of those traps using System Dynamics modeling.

### 3.2.1 The Anchoring Trap

The *Anchoring Trap* is a kind of cognitive phenomenon, where the mind of human being assigns disproportionate weights to the "*first*" information. That means, the subsequent thoughts and judgments anchors to the initial thought. In System Dynamics modeling we capture the similar trap while we model various decision rules. For example, when we use a table function/look up function we convert the variable in the X-axis as the "*Ratio of Variable-A to Variable-A Normal*" or "*Ratio of Variable-A to Variable-A Initial*" as shown in **Figure 6**. So, whenever we make a ratio relative to a *normal* or *initial* value, we anchor it to them. Hence, this kind of modeling is a representation of *Anchoring.* Hence, we need to check whether the decision rule has not got into an *Anchoring Trap.* If we believe it could be trap, as a remedy we have to *de-anchor* and test the effect. The manager can reflect himself through the model whether he is into an anchoring trap or not.

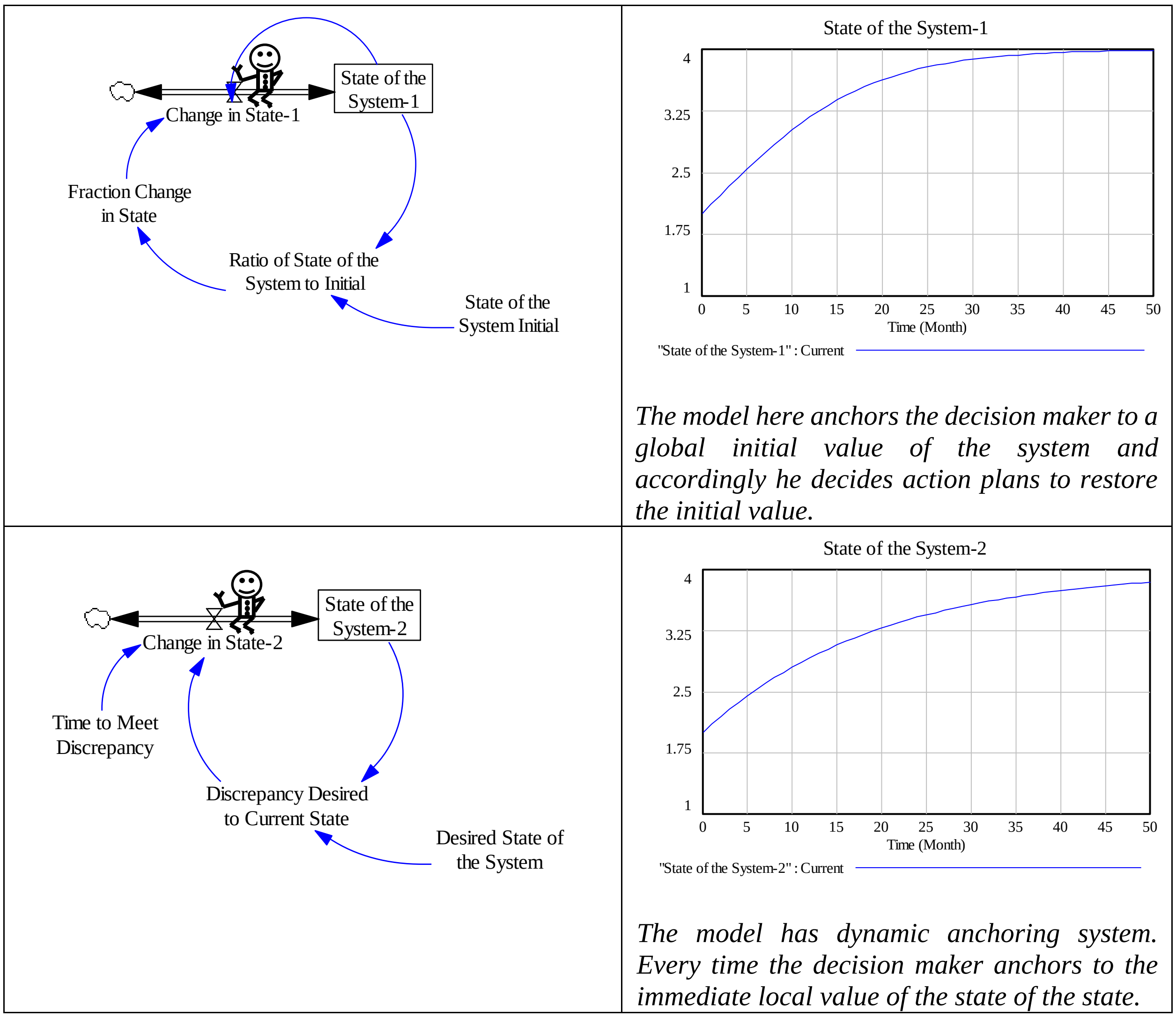
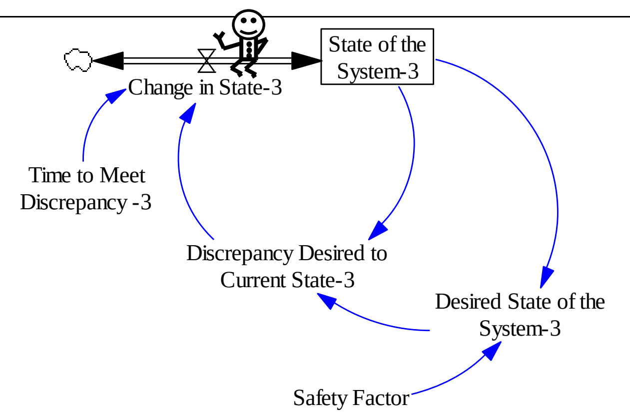
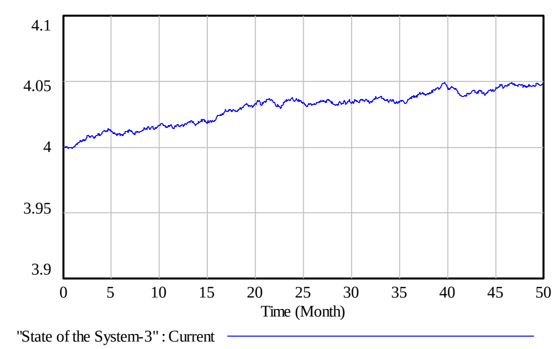



**Figure 6: System Dynamics Models of *Anchoring Trap***

### 3.2.2 The Status Quo Trap

The status-quo trap leads to a kind of anchoring trap with varying intensity of anchors. The decision maker always try to retain the previous state of the business. For example, if the sales in the last quarter has been 500 units and considered to be fairly good, then a manager under *Status-Quo Trap* would like retain it in the next quarter. Hence, he would practically try to ensure to hit the sales target close to the 500 units. Specifically, he would be happy to be at 500 ± 10 units of sales. This is a kind of anchoring mechanism, which dynamically change to retain the original status. The variation of ± 10 units is defined to be a random variable having a uniform distribution varying between –10 and 10. ***Figure 7*** shows a System Dynamics model of a *Status-Quo Trap.*




*The model here anchors the decision maker to retain the previous status of the state of the system. Thus, the initial value of the system is retained with little perturbations.*

**Figure 7: System Dynamics Models of *Status-Quo Trap***

### 3.2.3 The Sunk-Cost Trap

The decision makers are biased with *Sunk-Cost Trap*, when they make choice in such a way that they should justify their past choices, which no longer might valid. For example, a firm is making investment decisions based on the past returns on investments. More the return on investment the firm decides to invest more with the objective of high returns. If because of certain reason, there is less return than desired, the investors would still continue pumping in more money with the expectation of high return and turn-around of loss. The expectation of the investors are built up by the past trend of good returns on investments. **Figure 8** shows a System Dynamics model of a *Sunk-Cost Trap.* The *Sunk-Cost Trap* is due to the presence of *Delays* in believing to the changed reality. The decision maker still continues investing with his belief that the invested money is going to generate *returns* at the past rates, hence he continues investing further to ensure that.

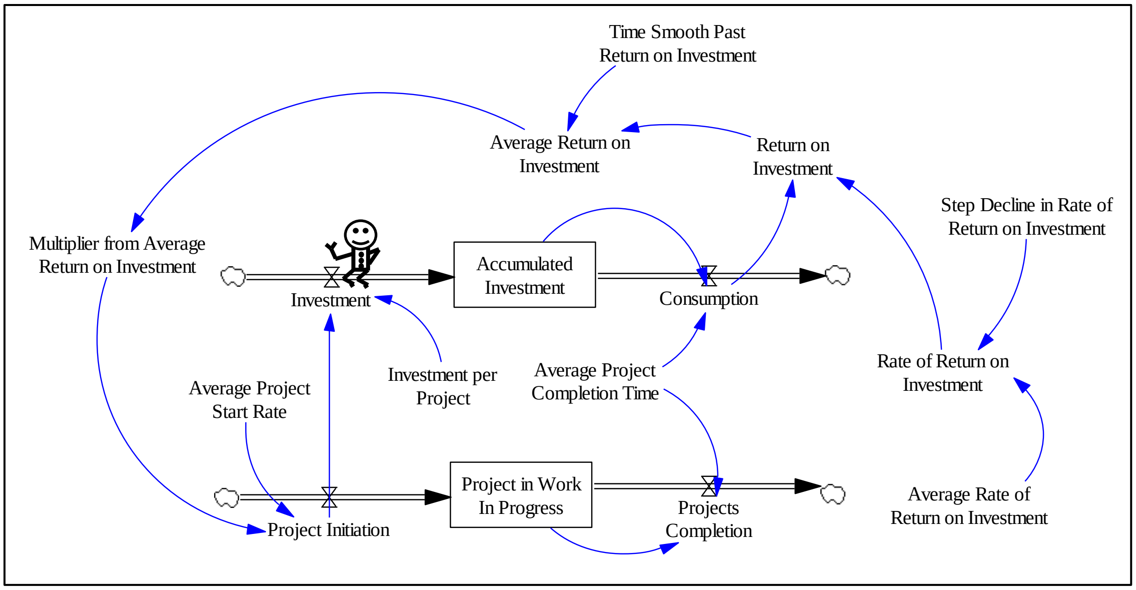



**Figure 8: System Dynamics Model of *Sunk-Cost Trap***

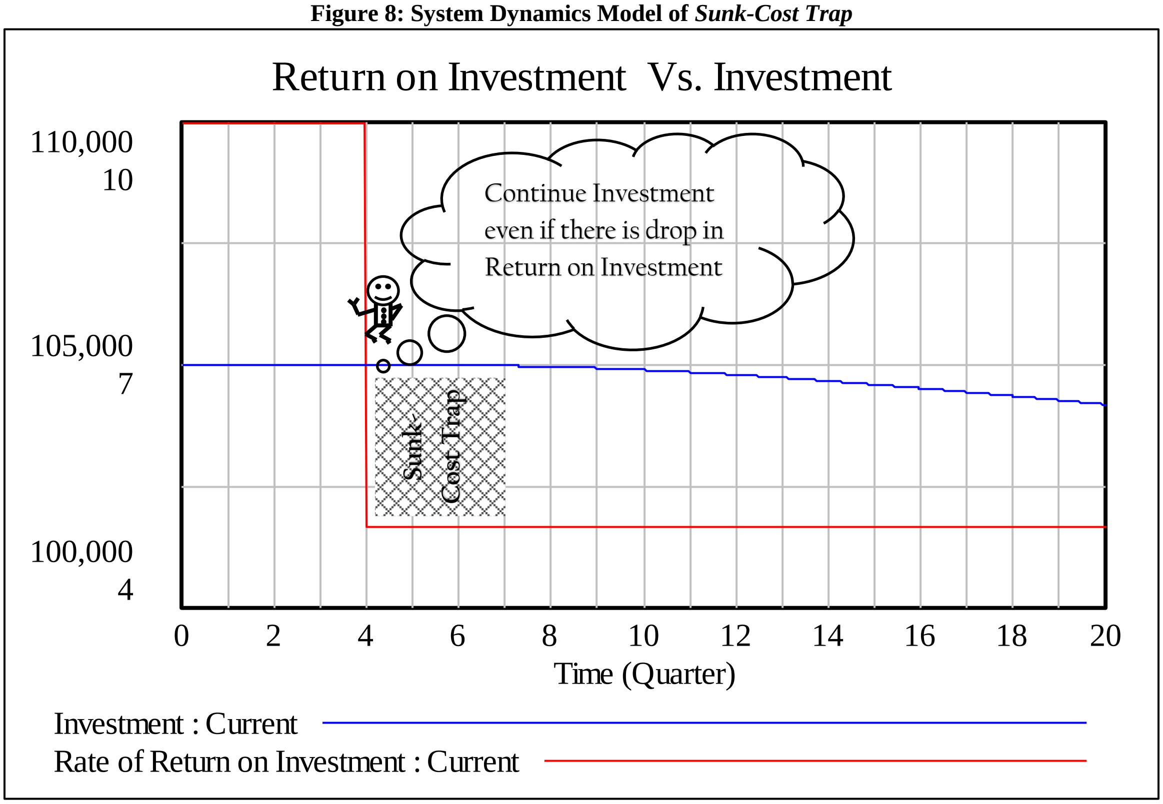



**Figure 9: Illustration of *Sunk-Cost Trap* through System Dynamics Model Simulation**

### 3.2.4 The Conforming Evidence Trap

The decision maker is biased in terms of seeking out information that support his existing instinct or point of view while avoiding the information that contradicts. Hence, the decision maker gives more weight to the supporting evidence and vice-versa while making decision rules. For example, more investment in capacity leads to more yield and hence more revenue. Hence, the decision maker develops a belief that it is required to invest in capacity in order to generate more revenue. However, more capacity generates more negative elements like, say, pollution, which ultimately reduces the yield. This is a contradicting information to the decision maker's belief, hence, his decision rule in order to generate more revenue still continues to be guided by the revenue-capacity investment relationship. The *Confirming Evidence Trap* will eventually lead to *Limits to Growth* and followed by *Overshoot and Collapse condition* as shown in **Figure 10** and **Figure 11**.

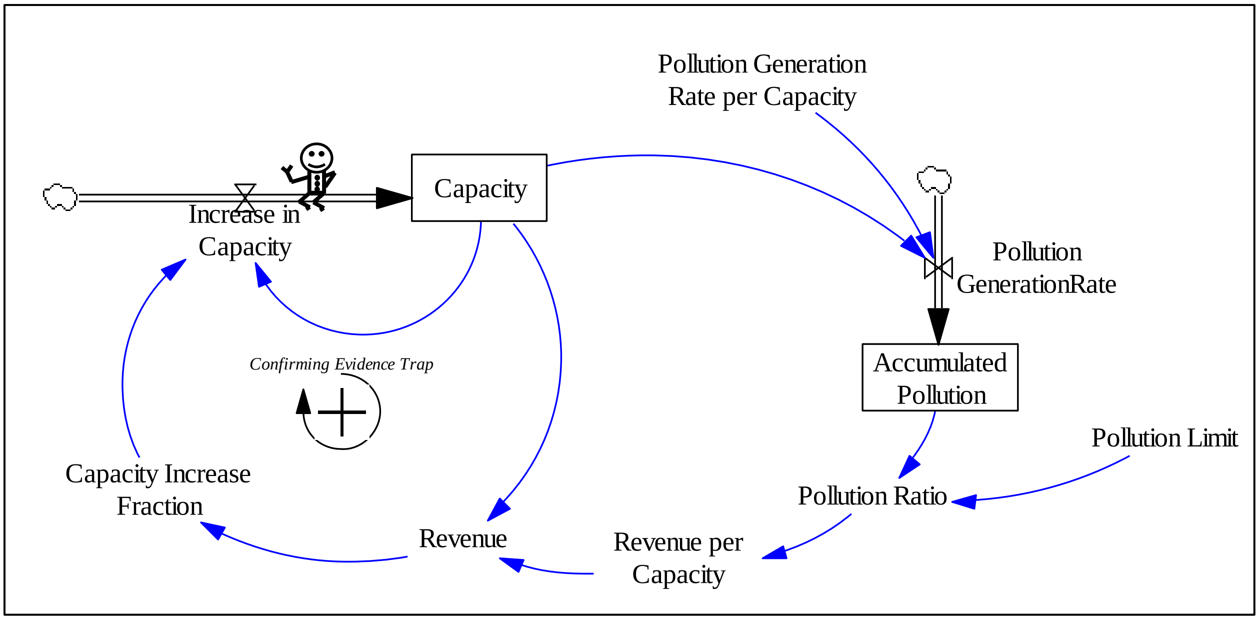



**Figure 10: System Dynamics Model of *Confirming Evidence Trap***

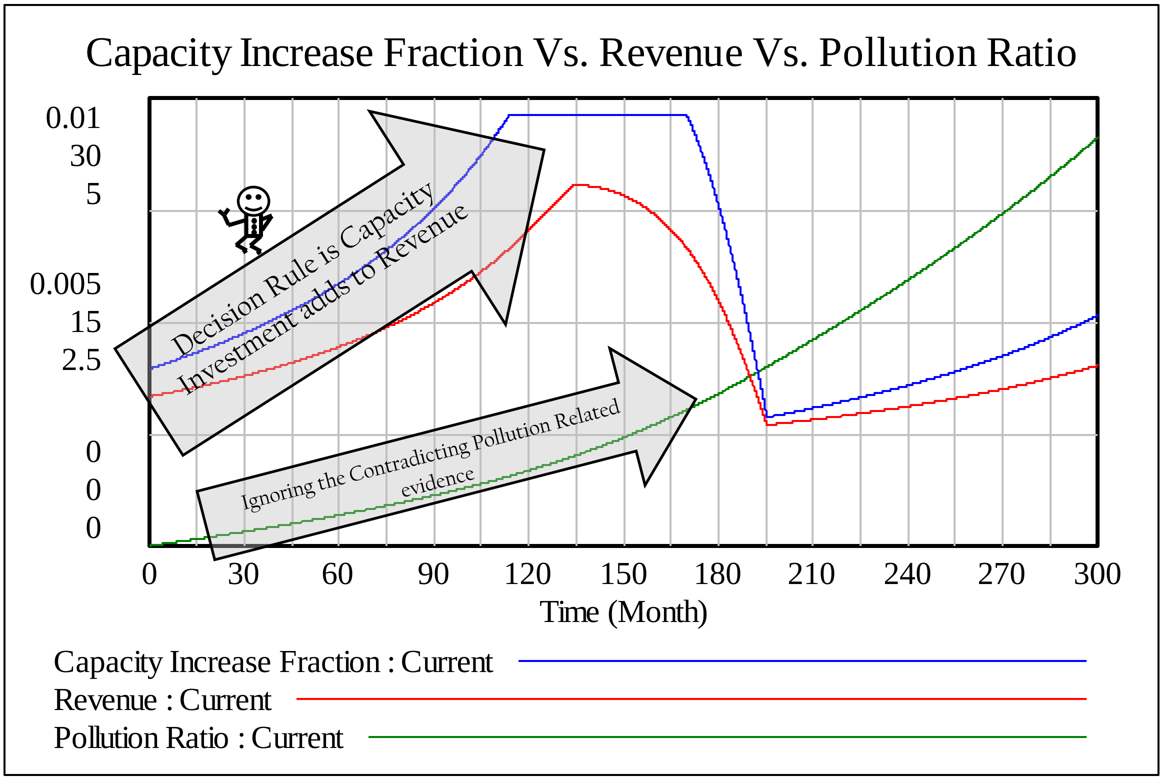



**Figure 11: Illustration of *Confirming Evidence Trap* through System Dynamics Model Simulation**

## 4. Conclusions

System Dynamics methodology, since its origin, has claimed itself to capture both economic and psychological variables in the development of models which represent dynamic decision making situations in a defined context.

System Dynamics modeling starts with a problem behavior in mind. The behavior might be dynamic in nature or could be a discrete visible problem being part of a dynamic problem. Whatever is the case it the dynamic nature of the problem is of our concern. The system dynamics modeling has two parts: firstly, the model is built based on the past problem behavior and its underlying structure and secondly, simulating the model for generating future behavior. The decision rules are usually captured in the model. The discrete decision processes are ingrained into the model structure. The model are usually used to understand the effect of in-built decision rules as well as evaluating the impact of array of decisions in the past as well as in the future. Hence, the model helps to understand not only the discrete decisions but also understanding the meta-level decision making process. Rigorous model testing methods proposed in System Dynamics modeling methodology helps in capturing the decision making situation more closely towards *reality*.

System Dynamics modeling process includes: (1) consideration of whole system and holistic view of the system—representing closer to the *reality*, (2) building a *valid* structure of the context, i.e. system—capturing the *heuristics*, if any, (3) developing a Causal Loop Diagram—capturing the *feedback* relationships, (4) building Stock-Flow Diagram—capturing delays, beliefs, forecasts, estimation errors, probabilities, cognitive and emotional variables, and non-linearity through mathematically defining them, (5) evaluating the model credibility—testing the *bias* of the decision maker, revising the structure, questioning the beliefs, understanding the sensitivity of factors, and (6) simulating over computer platform—making repeated experiments with JDM processes and learning. Hence, the System Dynamics modeling for any decision making situation is more *exhaustive* and *robust* and is away from critique of too much rationality assumption.

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