CHAPTER -1

INTRODUCTION AND SCOPE OF WORK

"Everything should be as simple as possible, but not simpler" (Albert Einstein)

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1.1 INTRODUCTION

Water, one of the basic life supporting systems on the earth, has always been a very important factor in the social, cultural, economic and ecological development of human civilization. Pollution of surface water resource like river is largely a problem due to rapid urbanization and industrialization though rivers are an important component of the natural environment and need to be protected from all source of pollution as man's own survival depends on sustainability of river. The large-scale urbanization due to population growth, generation of industrial effluents, cattle farming in riverbank, idol immersion in rivers affects the water quality of river like non-tidal Mahananda River in North Bengal. Point sources of pollution include domestic or industrial discharge directly or via pipeline connected to the river system. Three major water quality parameters Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), Dissolved Oxygen (DO) and pH are taken into account to develop mathematical model by using some statistical methods namely graphing, curve fitting and correlation regression etc. The water quality model has been developed with the objective of describing the water quality parameters and their comparative study and forecasting. Since uncertainty is an inevitable component of all predictions, the analysis of uncertainty in river water quality modeling has been discussed in this thesis. Since the soil of North Bengal is highly porous, the impact of porosity factor (Das, Barman, Dey 2006) of the riverbed and application of Darcy's law are analyzed.

The quality of water in many rivers in India continues to deteriorate at unprecedented rates, and in the process compromising the health of aquatic ecosystems, as well as the well being and livelihoods of some water users. Catchment based land activities generate waste that is delivered into and transported by rivers. The diversity of catchments and their rivers is often reflected by an assortment of water quality problems including eutrophication, increased salinity, increased turbidity, acidification and toxicity and the deteriorating quality of water in rivers presents a major challenge to the nation.

The dissolved oxygen (DO) concentration is a primary measure of a stream's health, but the dissolved oxygen concentration responds to the biochemical oxygen demand (BOD) load. Many streams and rivers in India have suffered from DO deficit, which is very critical to aquatic life. Investigators have continuously studied the dissolved oxygen uptake characteristics in stream water in relation to different sinks and sources in order to develop mathematical models describing the DO consumption. The minimum value of the DO concentration has been of particular significance in wastewater treatment design calculations and to regulatory agencies.

Water quality modeling in a river has developed from the pioneering work of Streeter and Phelps (1925) who developed a balance between the dissolved oxygen supply rate from reaeration and the dissolved oxygen consumption rate from stabilization of an organic waste in which the biochemical oxygen demand (BOD) deoxygenation rate was expressed as an empirical first order reaction, producing the classic DO sag model. When the dispersion process is considered, the governing equation becomes a partial differential equation. However, the effect of dispersion on BOD and DO in small rivers is negligible (Li, 1972; Thomann, 1974; McCutcheon, 1989). Adrian and Sanders (1998) developed an analytical solution for the DO sag equation which incorporated a second order BOD reaction, but their development involved integration of cumbersome equations.

Obviously, there is a long tradition and considerable justification to continue describing the DO sag in a stream using first order BOD reactions although there are applications for BOD reaction orders that are other than first order. Respirometry is a versatile method for measuring the degradation and the oxygen uptake characteristics of a wide variety of domestic and industrial wastewaters (Young and Cowan, 2004). Multiorder BOD data from Hewitt, *et al.* (1979) encouraged Adrian *et al.* (1999) to develop a DO sag equation for the three-halves order BOD reaction and a multiorder BOD reaction (Adrian *et al.* 2004). However, their development contained tedious mathematical expositions. The literature on BOD reaction orders which are less than first order has been reviewed by Adrian and Sanders (1992-93) while Adrian *et al.* (1999), Adrian and Sanders (1998), and Adrian, *et al.* (2004) reviewed three-halves order, second order, and multiorder BOD reactions, respectively.

First, this study is to demonstrate application of the Laplace transform method, which provides a user friendly approach to solution of differential equations, to develop a DO sag equation for a river in which a second order relationship describes the BOD decay of the loading to the river. Secondly, this study is to review the relationships which describe a three-halves order BOD reaction and have been applied to estimate BOD parameters, then to incorporate these BOD relationships into the differential equation for dissolved oxygen for a stream. Because of its ease in application the Laplace transform method is selected to solve the dissolved oxygen sag equation. Also, a methodology for locating the minimum dissolved oxygen concentration in a stream is developed. Then, examples are presented to illustrate application of the models and to compare results for DO concentrations with those predicted with a first order model.

This study also explores data accumulated between 2001 and 2006 to investigate long term and spatial trend in water quality data with respect to the major pollution indicator variables; pH, DO, BOD, COD in the Mahananda River.

1.2. SCOPE AND OBJECTIVE OF THE WORK

The main objectives of this study are as follows:

1. To develop a Mathematical model of the effect of organic pollution, defined as BOD, DO and COD. The result obtained from developed model has been compared with actual data to check the predicted variances. In the first comparison, DO values from six sites of the Mahananda river in North Bengal, taken at different seasons of the year, were fitted into the model along with times of the travel between those stations. In the second comparison DO and COD data from West Bengal Pollution Control Board (WBPCB) laboratory simulating movement of water downstream from the source of pollution were compared with values predicted by the model. In both cases, the data agreed well with the prediction of the model.

2. To develop the DO sag equation for a second order BOD model using the Laplace transform and the convolution integral to simplify the mathematical solution of the model equation.

3. To review the relationships which describe a three-halves order BOD reaction, then to incorporate these BOD relationships into the differential equation for DO for a stream, with application of Laplace transform in solving the DO sag equation.

The scope of this study includes the development of the second and the three-halves order BOD models using the new approach, the Laplace transform method, which was selected to solve DO sag differential equations because of its ease in application. Also by using various statistical tools the qualitative behavior of the three water pollution parameters named DO, BOD and COD are discussed.

1.3. Concept of Modeling and Simulation:

The process of developing model or making simplified abstract representation of real-world events / activities or systems by capturing their behavioral characteristics are known also as modeling. Model building helps scientists, Engineers and researchers in better understanding of the system. It better explains the past behavior and predicts future behavior of the system. It also helps for better and efficient planning and for evaluating policies and strategies of controlling the system in a desired fashion without disturbing it.

It is in human nature to want to understand dynamic systems, control them, and above all predict their future behavior. During the last century, this desire has lead to inter-disciplinary research into modeling and simulation, bringing together results from mathematics, computer science, cognitive sciences, and a variety of application domain-specific research. Modeling covers the understanding and representation of structure and behavior at an abstract level, whereas simulation produces behavior as a function of time based on an abstract model and initial conditions.

Mathematical modeling is a fast developing area of research and development field, which has a tremendous scope with respect to Environmental planning and conservation. Here simulation models are built or developed and experimented in nature. Deterministic Models can be developed for Water quality to study the impacts or movement of BOD, COD, and DO etc of the river.

The following mathematical tools are most frequently used in the development of models.

1. Set theory and Transformations:— Mostly used to represent any kind of model and it is employed in the development of state change of state models.

2. Matrix algebra: It is concerned with the description and manipulation of lists and tables of numbers.

3. Difference and Differential equations: These are used to develop models that describe quantatively the way systems change over time.

A mathematical model is a qualitative representation of a system based on mathematical relationships. Actually models are built in order to:

- understand functioning and internal structure of a system
- program measuring campaigns or positioning sensors
- monitor the system and control interventions

Building a model involves a number of steps, but it is not a straight procedure, as illustrated in Figure 1.1. Where more than one model is possible for a judicious choice of a particular model based on any system physical simulation is very important.

The models of any physical system can be classified into two class viz. deterministic models and probabilistic models.

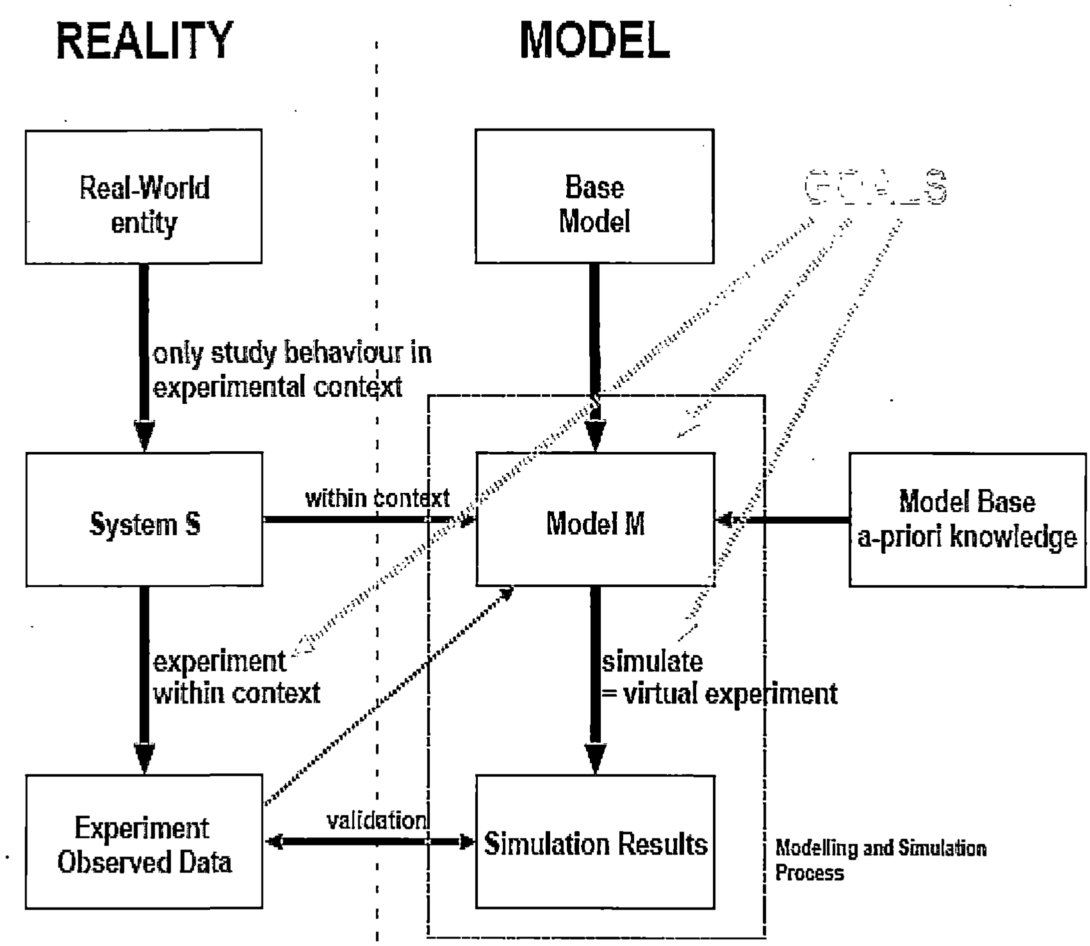


Figure 1.1: Modeling and Simulation

Deterministic models are those in which, all parameters and functional relationships are known with certainty. In case of probabilistic models at least one parameter or decision variable is a random variable. These models reflect to some extent the complexity of the real world and uncertainty surrounding it.

Static models are time independent, so they are useful to represent average values (e.g. energy balances in ecosystems). The relationships between inputs, disturbances and outputs are instantaneous since they are algebraic ($y=f(u, d)$), and they are based on mass and energy static balances and on static equilibrium equations. Dynamic models describe the behavior of time-varying quantities, and they are necessary to study the impact of any internal structure and / or external time-varying stimuli (e.g. populations dynamics, energy fluxes in ecosystems, etc.). These parameters are based on differential equations. Generally the models are based on differential equation of the following two types:

- Ordinary Differential Equations (ODE), e.g. continuous population dynamics
- Partial Differential Equation (PDE), e.g. pollutants diffusion

Numerical models can be statistical, stochastic or deterministic.

A statistical model doesn't try to explain causal connections nor internal dynamics in the system, just traces the overall characteristics of the available data sets. However, we can make a qualitative deduction on phenomena that generated the data, their statistical properties and recognition of anomalous data. A stochastic model reproduces the temporal progress of data without the claim of understanding this progress. It is useful for predictive intents but doesn't improve the knowledge of the system, and its use must be preceded by a structural analysis in order to establish causal input / output correspondences; what's more, for its calibration it needs a huge amount of data even if its structure is very simple. It is advantageous when we want to obtain an operative instrument that reproduces at best the observed output.

Deterministic models try to explain the internal mechanism of the process. The complexity of the model depends both on the available knowledge and the use we have for the model. A sound knowledge of the fundamental laws that rule the system is necessary.

Actually model gives an accurate description of a system within the context of a given experimental frame. The term "accurate description" needs to be defined precisely.

Usually, certain properties of the system's structure and/or behaviour must be reflected by the model within a certain range of accuracy.

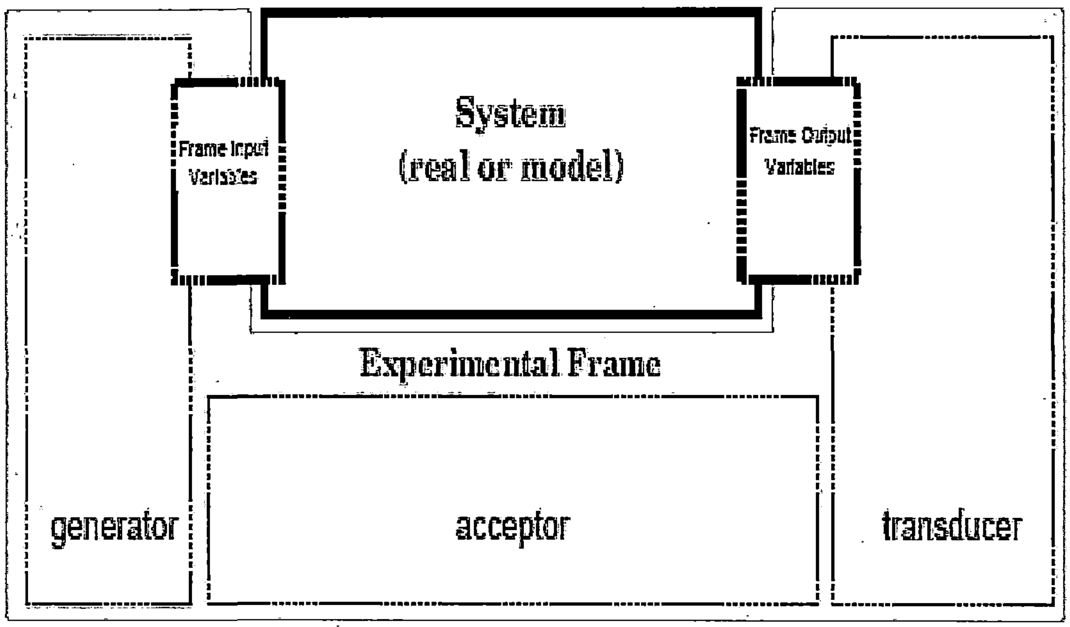
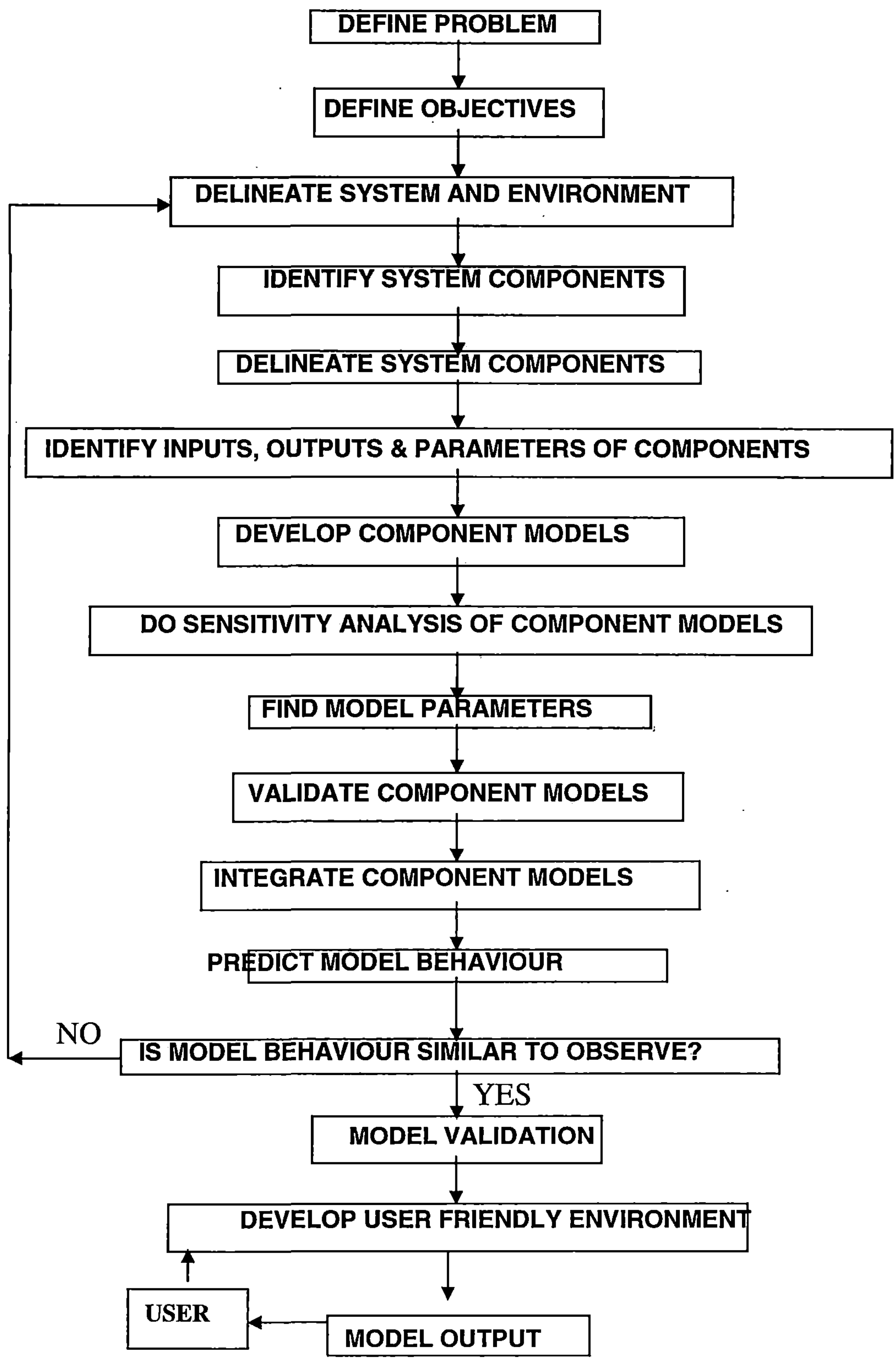


Figure 1.2: System versus Experimental Frame

There are also fuzzy models that enable to deal with concepts defined descriptively (e.g. High, Low, Much, Few...); they are based on logic-deductive reasoning, and are built of a number of "rules" like: IF<this happens>THEN<this is true>. Each proposition in not TRUE or FALSE, but its degree of truth can vary with continuity between 0 (false) and 1 (true). To develop fuzzy reasoning we need fuzzy algebra in order to have a fuzzy object that, after being elaborated, needs to be defuzzyfied in order to be quantified and used deterministically.

Model validation is the process of comparing experimental measurements with simulation results within the context of a certain experimental frame. When comparison shows differences, the formal model built may not correspond to the real system. A large number of matching measurements and simulation results, though generates confidence, however does not always prove validity of the model.

The model methodology can be described as follows



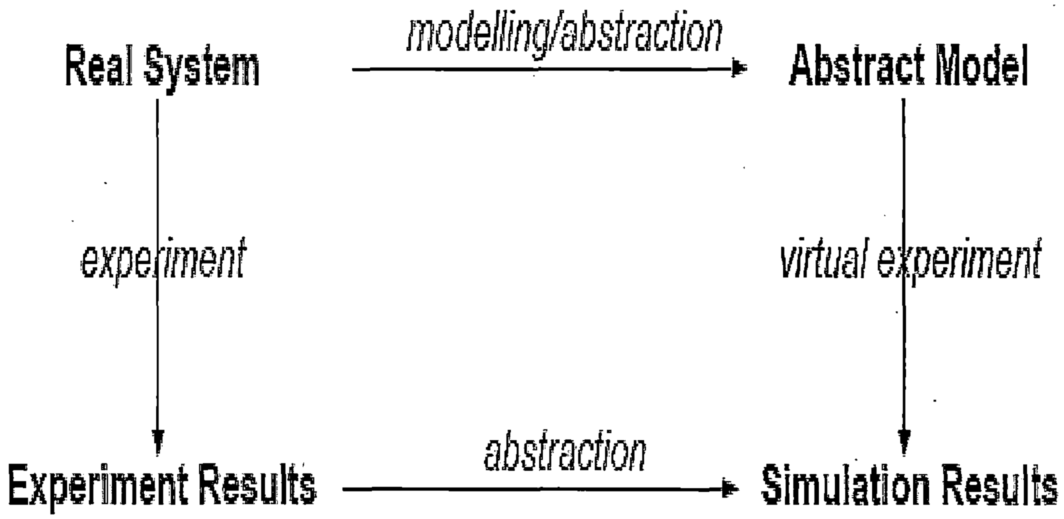


Figure 1.3: Modeling – Simulation Morphism

Various kinds of validation can be identified; *e.g.,* conceptual model validation, structural validation, and behavioural validation. *Conceptual validation* is the evaluation of a conceptual model with respect to the system, where the objective is primarily to evaluate the realism of the conceptual model with respect to the goals of the study. *Structural validation* is the evaluation of the structure of a simulation model with respect to perceived structure of the system. *Behavioural validation* is the evaluation of the simulation model behaviour. An overview of verification and validation activities is shown in Figure 1.4. It is noted that the correspondence in generated behaviour between a system and a model will only hold within the limited *context* of the experimental frame.

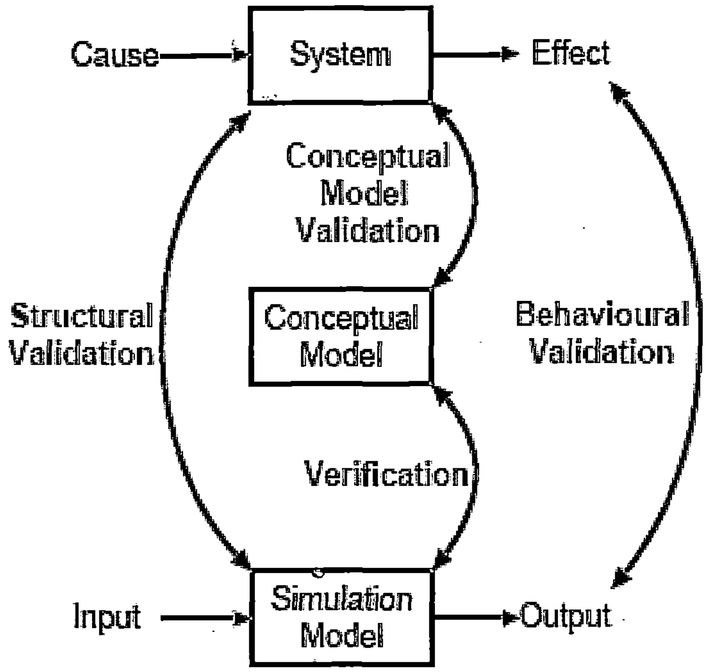


Figure 1.4: Verification and validation activities

Consequently, when using models to exchange information, a model must always be matched with an experimental frame before use. Conversely, a model should never be developed without simultaneously developing its Experimental Frame. This requirement has its repercussions on the design of a model representation language.