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JURNAL AKADEMIK

The Art of Modelling	YAP YIN @ YAP KEE KONG
Employment: Focus on Housework	WEE CHONG HUI
Evaluating Effectiveness of Teaching	SICK GOH NGONG
Towards A More Meaningful Financial Statement	WEE SHU HUI
The Independence of the Auditors – Fact or Fantasy	ALLAN CHANG AIK LENG
Masalah Pembelajaran Pelajar-Pelajar Institut Teknologi Mara Cawangan Sarawak	HAMIDAH ABDUL NINGGAL
Prinsip-Prinsip Pembentukan Huruf Cina	LOW KUEK LONG
Perkembangan Imbangan Pembayaran Malaysia 1978-1987	ROSITA HJ. SUHAIMI

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THE ART OF MODELLING

by

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To a layman, the word "model" is associated with the photogenic models he sees in fashion magazines. Apart from being a noun, the word "model" can also be used as an adjective and a verb. As an adjective "model" implies a degree of perfection or idealization as in reference to a model home, a model student or a model husband. As a verb "to model" means to demonstrate, to reveal, to show what a thing is like.

Scientific models, on the other hand, are used as a representation of any subject of enquiry such as objects, events, systems and processes. The most important function of scientific models is to enable a researcher to study how changes in the features of a model entity can affect other features or the whole entity. Hence, through manipulation of the model, the researcher can gain further insights into the problems concerning the operations of an entity. In any formal research into a process or a system scientific modelling plays a very important role in reducing cost and time. Instead of manipulating an actual object or process, its model is being manipulated. This advantage is immediately apparent in manipulating the model of a complex industrial organisation.

In general the advantages of scientific models over verbal description are:—

(a) The problem can be described more concisely

(b) The overall structure of the problem can become more comprehensible

(c) The cause and effect relationships of the variables can be considered simultaneously

(d) The representation of an event, system or process by a scientific model forms a bridge for using advanced mathematical techniques and electronic computer to solve the problem.

The salient features of scientific models can best be observed by considering progressive evaluation of models from the simplest to the most sophisticated form.

Iconic Model: This is the simplest form of scientific model. The term is derived from the Greek word "icon" which means image. Hence an iconic model is the image representation of an object. Examples of iconic models are toy cars, photographs and sculptures. The field of chemistry has produced iconic model of the atoms and molecules while in the field of astronomy, iconic models of parts of the universe have been produced.

In general, the construction of iconic models requires the actual properties of the objects to be subjected to metric transformation, i.e. they are either scaled up or scaled down before they are represented by the iconic model. Such a model is normally used to represent static or dynamic things at a point in time.

In the construction of iconic models, properties of the objects which are not essential for the purpose of the study are omitted. For example, in the construction of an iconic model to represent a car park it is not necessary to show the upholstery of the model cars.

Iconic models have limited use because they cannot be used to represent processes or systems which are dynamic in nature. For example, the effect of changes in a production line cannot be represented by an iconic model. Furthermore, the physical properties of the models are fixed and hence cannot be manipulated.

Analogue Model: In an analogue model, the actual properties of objects, events and processes are transformed into analogous properties. For example, contour lines are used to represent elevation and relief of land, while graphs are used to indicate quantitative relationship between two variables.

The manipulation of analogue models is easier than the manipulation of iconic models. For instance, if changes occur in the land formation, the corresponding changes can be easily done to the contour lines which are two-dimensional. In the case of iconic model the corresponding changes are difficult to incorporate into the model because of its three-dimensional nature.

Entities or systems which are dynamic in nature can easily be represented by analogue models. For example, a production process can be represented by an electrical circuit. Any changes in the inputs of the production process can be represented by varying the voltage or resistance of the circuit. The analogue models can also be constructed to represent many different processes of the same type. In this respect, the analogue model is more general than the iconic model.

Symbolic Model: In the symbolic models, the components and variables are represented by mathematical symbols. Hence, the term mathematical model is sometimes used to denote the symbolic model. For example, consider the classical inventory control model

$$TC = XC_o + \frac{X}{Q} C_1 + \frac{Q}{2} C_2$$

where

TC	=	Total inventory cost
X	=	Constant demand per unit time
Q	=	Lot size
Co	=	Unit cost per item
C1	=	Replenishment cost per lot
C2	=	Holding cost per unit per unit time

The symbolic model is by far the most comprehensive and useful type of scientific models. Many processes relating to production and management are represented by symbolic models. Some of the areas are in the field of inventory control, allocating, queuing, replacement bidding, decision making and linear programming.

In general, the format of the symbolic model is as follows:-

$$E = f(X_i, Y_j)$$

Where

E	=	Measure of effectiveness
f	=	The functional relation between the variables X_i's and Y_j's.
X_i	=	The variables which can be controlled by management action
Y_j	=	The uncontrolled variables of the system

The extraction of a solution of such a model consists of determining the values of the controlled variables Xi for which the measure of effectiveness is optimised.

For example, in the classical inventory control model, the measure of effectiveness E is the total inventory cost TC, the uncontrolled variables are X, C_0, C_1 and C_2 while the controlled variable is the lot size Q. The functional relation f indicates how the X_i and Y_j variables are related to each other. The objective is to find the lot size which minimises the total cost TC.

Construction of Symbolic Model

The first phase in the construction of a symbolic model is the process of problem formulation. The various components which constitute a problem are identified. The steps involved in problem formulation are as follows:-

(a) Identification of decision maker or group of decision makers of the system under study

(b) Identification of all the pertinent objectives relative to the problems

(c) Identification of alternatives which enable the objective to be attained.

(d) Identification of the constraints of the system

(e) Identification of the controlled and uncontrolled variables pertinent to the problem

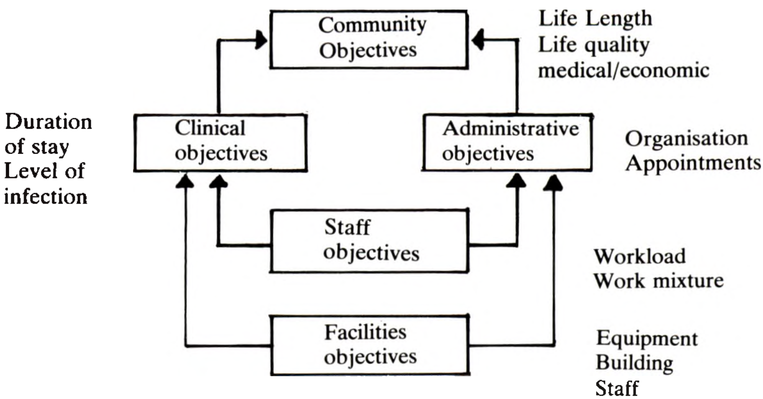
(f) Identification of the measure of effectiveness i.e. the decision criterion or set of criteria

Identification of Decision Makers

It is important for the researcher to identify the ultimate decision makers. If a course of action is to be prescribed, it is essential that the decision makers be isolated since decision makers with different value system would prefer different alternatives in general. For example, who is going to make the final decision on the production policy? The production controller? The sales manager? The chairman? Consider the problem of replacing buses. The economic policy may result in running the less modern buses. Who are the decision makers? The public? The transport department general manager? The minister of transport?

Having identified the decision makers, the researcher has to find out from them their objective or set of objectives they wish to attain. In a system or an organisation there may be several levels of objectives. Consider the different levels of objectives in health services.

LEVELS OF OBJECTIVES IN HEALTH SERVICES



Each level of objectives is evaluated in terms of the lower levels

The time frame of the model must be fixed because some objectives such as the scheduling of time table for ambulance drivers are short term in nature while others such as the recruitment of specialists are long term.

Objectives may seem to conflict with one another. If any conflict arises, priority is given to the higher level objective.

In problem formulation each level of objectives must be operationalized as organizations tend to state their objectives in conceptual form. For example, one of the objectives of the National Productivity Center is "raising the standard of management including supervision at all levels."

To operationalize an objective means to define the objective in such a way that programmes can be carried out to attain it.

Identification of Alternatives

It should be noted that if there is only one way whereby the objective may be attained, then there is no problem. For a problem to exist, there must be at least two or more alternative causes of action to attain the objective. In the initial stage all possible alternative are identified, perhaps through a brain storming session. It is apparent that some alternatives are superior to others. Using the principle of dominance, all the inferior alternatives are eliminated.

Identification of Constraints

Constraints are any conditions or specifications which have to be satisfied. Constraints at various levels can be in terms of:–

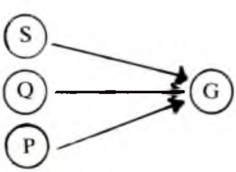
(a)	Physical Specification	=	Room height 2m Window size 1m
(b)	Environmental Specification	=	Temperature between 70 – 80^{o}F
(c)	Activities	=	No one has to walk more than 5 km in a day
(d)	Financial Specification	=	The building must not cost more than $10,000 p.a. to maintain

Identification of Variables

The controlled and uncontrolled variables are identified through the backward and forward identification techniques.

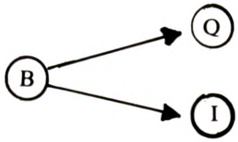
Backward Identification

In this case we simply ask what variables influence a given variable. For example, consider the variable customer goodwill G. It is influenced by service S, quality of product Q and price of product P.

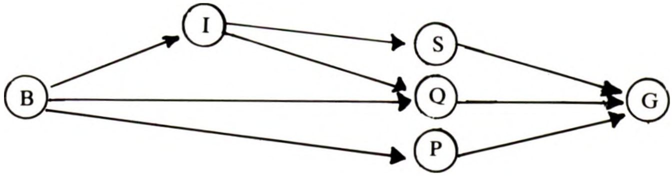


Forward Identification

In this case we ask what variables are influenced by a given variable. For example, the variable bonus will influence quality of output and increase in productivity.



It the forward and backward identifications are combined, then a network of variables is built up.



The efficiency of variable identification depends solely on the perception abilities of the researcher. Whether a variable is important depends on the degree of its influence. A variable may thus be ruled out or introduced on purely subjective grounds prior to the derivation of relation.

Identification of Criteria

A criterion is a rule used for judging or evaluating the output or consequences. Consider the example of an educational criterion. We are often faced with problem of choosing between different educational systems. Thus we may use lecture hall and large classes or more lecturers with smaller classes. A suggested criterion might be, for a given outlay, the number of people who pass their examinations. Thus in the first instance we may have a larger intake and proportionally fewer passes and poorer overall quality, but in the latter we may have less intake but proportionally more passes and better overall quality. In the field of production, often production people are concerned with machine utilization. Full machine utilization is achieved by having a lot of work in progress. However, any breakdown in any section may result in delays in fulfilling some customer's orders. One must compromise between the two. Thus it can be seen that at the problem formulation stage there is a need to amalgamate the desires of different decision makers to produce a representative desire.

Model Construction

Having formulated the problem we have the basis for the construction of the symbolic model. The general form of the symbolic model is

$$E = f(Xi, Yj)$$

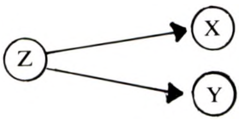
The variables Xis and Yjs which have been identified using the combined forward and backward identification methods are classified according to the following scheme :–

(a) Deterministic – Causal
Given X, then Y is predetermined
Example : X might be a production programme, Y might be manpower requirement

(b) Partial deterministic – Causal
Given X, then Y R (X)
Example: $l(x) < y < u(x)$

(c) Probabilitic – Causal
Given X then y has a known probability
Example: $P(y = Y/X) = P(Y, X)$

(d) Correlation – non-causal
Given X, Y there is a variable Z such that
Z is causally related to X
Z is causally related to Y
thus



For example X = rate of accident
Y = rate of rainfall

We cannot say that increase in rate of rainfall causes increase in the rate of accident. The unknown factor Z may be the conditions of the roads, condition of the cars, or even the sex of the drivers.

Having considered the interrelationship among the variables in the problem, the researcher selects the functional form next. There are two commonly used methods of model building.

(a) **A priori method** – in this method we select variables based on assumed understanding of this situation and then postulate a model.

(b) **Variational method** – in this method, we vary the known parameters by small amounts and build up knowledge of behaviours for general situation.

Example:

$$dy = \frac{dy}{dx_1}(dx_1) + \frac{dy}{dx_2}(dx_2) + \frac{dy}{dx_n}(dx_n)$$

This is an example of evolutionary control of chemical process. The main aim of the researcher is to search for the optimal or best solution represented in symbolic form. In general there are three types of solutions, namely:

(a) **Analytic Solution:** This refers to the exact solution. Only in rare circumstances can we give an analytic solution to a symbolic or mathematical model

Example: Economic Lot Size $Q = \sqrt{\frac{2 \times C_1}{C_2}}$

In many scheduling problems it is not possible to express the total production time as a function of the parameters of the policy. Such a solution, if it exists, will facilitate routine investigation of sensitivity of the model. However, even if the analytic solution does not exist, it will not affect the usefulness of the model because after all the model is not the exact representation of the real world; it is just an idealized one.

(b) **Numerical Solution:** If analytic solutions cannot be found, then numerical methods are used to produce practicable computational routines.

Example. In Linear Programming, the measure of effectiveness Z cannot be expressed as a function of the constraints. However the optimal solution can be found using the simplex algoritum which is essentially an iterative method.

Example: In the scheduling problem, the theory of Markov processes may provide a routine numerical computation for each set of parameters.

(c) **Simulation:** There are situations in which numerical techniques cannot provide any solutions to a model. We then resort to the technique of representing the physical behaviour of a system in such a manner that this behaviour can be condensed into a much shorter space than the real time of the system. The "actual" behaviour is then observed, each alternative considered and the choice made on the basis of this behaviour. Simulation is relatively simple and requires virtually no mathematical knowledge, but it is tedious, time consuming and limited in its coverage of alternatives. It also requires the use of a large computer.

Testing the Model and Solution

Before the implementation of the solution, a symbolic model must be tested for its validity. A model is valid if it predicts the relative effects of the alternative courses of action with sufficient accuracy to permit a sound decision. Such a test of validity can only be carried out by implementing the solution. Before such a test is carried out the following preliminary test should be carried out:

(a) Check for obvious errors and oversights such as the exclusion of relevant variables and inclusion of irrelevant variables in the model.

(b) Check whether the correct interrelationships among the variables are incorporated into the model.

(c) Check whether certain input parameters have been estimated accurately.

(d) Check to ensure that all mathematical expressions are dimensimally consistent in the units they use.

If there are any errors detected as a result of the preliminary tests, the model is reconstructed. The new model is then tested by varying the input parameters are decision variables to see if the output behaves in a plausible manner.

The model is then tested retrospectively by using historical data to reconstruct the past in order to determine how well the model and the resulting solution would have performed if it had been used. The disadvantage of such a test is that it assumes that the past is representative of the future.

Using the historical data, the solution of the model is prescribed to the ultimate decision maker. Using his subjective experience he could usually decide whether the solution is plausible or whether it is too revolutionary.

Implementation and Control

When a model has been tested and improved upon, there is no guarantee that it can be used repeatedly without getting obsolete. The reason is that in the real world conditions are changing constantly and such changes might invalidate the model. Hence there is a need to maintain a general surveillance of the situations in the real world.

Nowadays most researchers incorporate the component of sensitivity analysis into the model before they pass over to the management for implementation. In sensitivity analysis, the parameters of the model are varied over a range of possible values to determine the degree of variations in the solution. Furthermore, process control chart and statistical quality control are also used to monitor and control the model so that the model, its solution and resulting course of action are modified accordingly.

The research team should encourage the management to be involved in the formulation and evaluation of the model to ensure active support from the top management at the implementation stage. Being responsible for constructing the model the research team should not be given total control over the implementation phase because they might fall in love with their pet model thus rendering them unreceptive to any constructive criticism.

In concluding it should be emphasized that there are no fixed rules in modelling. By its nature model construction requies considerable ingenuity and innovation. It is hoped that the above description may be viewed as a "model" that has roughly described the process of constructing a model to represent the real world for the purpose of decision making.

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