# CISD -- A NORMATIVE METHOD FOR TECHNOLOGY ASSESSMENT

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## ABSTRACT

The formal KSIM (Kane's SIMulation) model is equivalent to a particular system dynamics (SD) model. On the basis of this equivalency, we use the KSIM and cross-impact concepts to simplify the SD modeling steps, and a new procedure -- CISD from the abbreviation for Cross Impact System Dynamics which is technically simpler and more normative, has been introduced. CISD is well applied in the field of Technology Assessment (TA). An example for TA of agricultural chemicals with CISD is presented. A general computer program for CISD which is called CISD-FORTRAN makes CISD procedure more widely used with facilities even for nonspecialists.

## INTRODUCTION

Technology assessment, a relatively new and innovative concept emerged in the middle of the 1960s, began to change the common ideas people had for a long time about the social and economic functions of science and technology. It promotes the public policy and decisionmaking process for programming technological developments. The term "technology assessment" was first appeared in a report submitted to the U.S. Congress by the former congressman Emilio Q. Daddario in 1966, and it was described as "a form of policy research which provides a balanced appraisal to policymaker". "It identifies policy issues, assesses the impact of alternative courses of action, and presents findings. It is a method of analysis that systematically appraises the nature, significance, status, and merit of the technological program".

Methods used in TA can be divided into three types: (a) qualitative methods, (b) quantitative methods, (c) modeling and simulation methods. System dynamics is one of simulation methods for TA. The "Limits to Growth" was the earlist and most significant application of SD to a problem-oriented TA project sponsored by the Club of Rome, thereafter, SD has been more noticably applied to different TA problems. However, we are facing difficulties to build a general TA model using SD because of its folloeing deficiencies:

1. A SD model lacks generalization. The model is directed to the specific problem and it suffers a lot of changes as the problem changes a little.
2. SD is technically complex. Modelers are required to be familiar with the system they are modeling and adept in the SD methodology and DYNAMO programming.
3. System struture and policies tested are based on modeler's intuition, the real decisionmakers are not parcitipative in the modeling process for some technical reasons.

In generally speaking, subjective and psychological factors play important roles in TA problems (both technology-oriented and project-oriented), therefore expertises of wide range are critical for a TA program. On the other hand, some TA programs are time-pressed, i.e., final policies for a technological utilization or development should be made in a short term because the recent technologies are speedly evolved and strongly competitive for commercial and economic purposes. All these call for a method with simplicity and generalization which not only can congregate the expertises in a model, but also can reflect the dynamic behaviour of second and higher order impacts which the technology under evaluation makes on natural enviornment, human society, sovereign economy and technology itself.

This paper will give a method which is called CISD from the abbreviation for Cross Impact System Dynamics. CISD uses a Cross Impact Matrix (CIM) to portray the causal interactions system elements, and the quantitative relations of system variables are expressed in the form of KSIM equations. CIM can be identified through Delphi, brainstorming and other methods. To some extent, CISD is a comprehensive combination of SD and KSIM. It is characterized by simplicity, conciseness and its standard format, and therefore becomes an effective method for TA.

## A BRIEF STUDY ON SD

### A General Model of SD

Causal diagrams or flow charts essentially indicate the causal interactions among system variables. These causal interactions are further divided into two specific types refered to as the material relation and the information relation.

The material causal relations determine the flow paths in flow charts. If two quantities are materially related, one of them, say $q_i$, will accumulate the net effect of the other quantity $q_j$, the quantity $q_i$ is called affected variable and $q_j$ affecting variable. More generally, causal relations of this type can be represented by the following differential equation when there are n affecting variables:

$$\dot{q}_i = f_i\,(q_1.\ q_2,\ \ldots,\ q_n) \qquad q_{i(t_o)} = q_{io} \qquad (1)$$

In physical meaning, material causal relations reflect the law of conservation of matter within the universe. Examples of this type of causality are the relationships of petroleum reserves to petroleum consumption, of savings to compounded interest, of population to births and deaths, only to name some. This type of causal relation can also delineates the dynamic, cumulative, and memory-possessing characteristics of the system. In flow diagrams, material flow paths are only through the levels and rates, the level equation gives the form of their relations:

```
L     L.K = L.J + DT*(RIN.JK - ROUT.JK)
N     L = L0
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$$\frac{dx}{dt} = \lim_{DT \to 0} \frac{L.K - L.J}{DT} = \lim_{DT \to 0} (RIN.JK - ROUT.JK)$$

$$= r_{in} - r_{out} , \qquad x(t_o) = x_o$$

The rate can be written in the form of the decision function

$$r = f(x,y,p) \tag{2}$$

therefore, we have

$$\frac{dx}{dt} = f(x,y,p) \qquad x(t_o) = x_o \tag{3}$$

where x, y, r, p are the vector forms of levels, auxiliaries, rates, and parameters respectively.

Information causal relations, on the other hand, determine the information path in a flow chart. Information is needed when decisions are made, therefore, the information path actually embodies the decisionmaking process. If two quantities are informationally related, the affected one will be decided by the affecting one but not accumulate the net effect of it over time, i.e., the information causal relations are memoryless, they affect each other instantaneously. This type of causality can be more generally expressed as a functional equation:

$$q_i = g_i(q_1, q_2, \ldots , q_n) \tag{4}$$

In system dynamics, its specific vector form is

$$y = g(x, y, p) \tag{5}$$

To conclude, all SD equations can be written in general form as equations (1) and (4), or in the vector form as equations (3) and (5). Level equations are obtained through integrating the equation (3).

$$x = x_o + \int_{t_o}^{t} f(x,y,p)\, dt = x_o + \int_{t_o}^{t} r\, dt \tag{6}$$

## The SD Modeling Process

Although many authorities have summarised the stages of the SD modeling process in their literatures, we here show a standard five steps of SD modeling:

1. Conceptualization model. Identifying and conceptualizing the problem under study literally, this may include problem definition, the purpose, condition and specific requirement of the model, reference behaviour modes, etc.
2. Causal diagram model. Reflecting different causal interactions among system variables.
3. Flow chart model. Representing the inner feedback structure of the system.
4. DYNAMO model. Quantifying the couplings of variables appeared in the flow chart.
5. Model tests. Sensitivity analysis, policy tests and analysis, model validity and development, etc.

## KSIM MODEL AND ITS SIMILALITY TO A SD MODEL

A general KSIM model can be written as follows:

$$\frac{dx_i}{dt} = -(c_i + \sum_{j=1}^{n} (a_{ij}x_j + b_{ij}\frac{dx_j}{dt}))x_i \ln x_i \qquad (7)$$

where $x_i$ are the state variables of the system, $i = 1, 2, \ldots, n$ $0 \leqslant x_i \leqslant 1$; $a_{ij}$ are elements of the state interaction matrix ($n \times n$) giving the impact of $x_j$ on $x_i$; $b_{ij}$ are elements of rate interaction matrix ($n \times n$) giving the impact of $dx_j/dt$ on $x_i$; $c_i$ indicate the impact of exogenous intervention on $x_i$. Equation (7) can be represented in matrix notation as:

$$\frac{dx}{dt} = D(x)\ (Ax + B\frac{dx}{dt} + C) \qquad (8)$$

where A, B, C can be aggregated in a combined matrix (A B C), the diagonal weighting matrix D(x) is defined as

$$D(x) = \begin{pmatrix} -x_1 \ln x_1 & & & 0 \\ & -x_2 \ln x_2 & & \\ & & \ddots & \\ 0 & & & -x_n \ln x_n \end{pmatrix}$$

Here any element $(-x_i \ln x_i)$ in matrix D(x) is called Kane's modulation function.

Equation (7) does not meet the requirement of the rule of consistency in system dynamics, however, by defining $z_j = dx_j/dt$ and enlargingthe conbined matrix the expression is equivalent to a consistent equation as

$$\frac{dx}{dt} = -(c_i + \sum_{j=1}^{n} a_{ij} x_j) x_i \ln x_i \qquad (9)$$

or in matrix form as

$$\frac{dx}{dt} = -(C + Ax) D(x) \qquad (10)$$

Comparing Eq. (10) with SD equation (3), we obviously find that the former is a particular form of the latter. Further assuming $r = (C + Ax) D(x)$, we shall write the equivalent DYNAMO equations for Eq. (10) as

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L      x.K = x.J + DT*r.JK
R      r.KL = -(C + A*x.K)*x.K*LOGN(x.K)          (11)
N      x = xo
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The equation set (11) represents a minimum submodel of SD flow diagram (shown in Fig. 1). A complete KSIM model consists of n submodels of the same form.

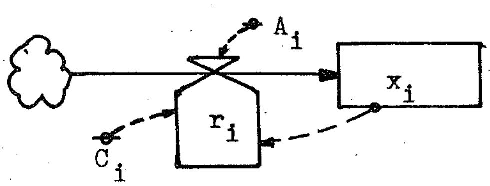


Fig.1 A minimum SD model

CROSS IMPACT SYSTEM DYNAMICS

## A Four Step Procedure

As discussed above, the KSIM model is equivalent to a specific SD model, this model is normatively structured by n minimum SD models of the same form. If we introduce a CIM (Table 1) to identify the causal interactions of system variables and the DYNAMO equations are written after the pattern of the equation set (11), a simplified four step modeling procedure CISD is established on the basis of previous SD modeling steps.

Step one -- conceptualization of the problem (the same as SD).
Step two -- structural interpretation. In this step, system variables are determined and initiated; a CIM which gives the interaction and its strength $a_{ij}$ between any two variables is identified through Delphi.
Step three -- DYNAMO model. The equivalent DYNAMO interpretation of KSIM relations is utilized.
Step four -- model tests.

Table 1 shows the general form of a CIM in CISD. Variables are

Table 1 The CIM in CISD

| affected variable \ affecting variable | $x_1$ | $x_2$ | ... | $x_n$ | c |
|---|---|---|---|---|---|
| $x_1$ | $a_{11}$ | $a_{12}$ | ... | $a_{1n}$ | $c_1$ |
| $x_2$ | $a_{21}$ | $a_{22}$ | ... | $a_{2n}$ | $c_2$ |
| ⋮ | ⋮ | ⋮ | $a_{ij}$ | ⋮ | ⋮ |
| $x_n$ | $a_{n1}$ | $a_{n2}$ | ... | $a_{nn}$ | $c_n$ |

binarily interrelated, the total number of elements in CIM is $n^2$. The most ostensible difference between CISD procedure and SD modeling process is the use of CIM to replace the the causal and flow diagrams for the purpose of indicating the system structure. CIM has a very normative form and always keeps the same whatever changes the system structure. This characteristic of CIM makes the CISD procedure simple and stardard.

Comparision Between SD and CISD

Some comparisions between the two are shown in Table 2.

Table 2. Comparisions between SD and CISD

| Comparisions in the aspect of: | SD | CISD |
|---|---|---|
| 1. characteristics | -Complex | simpler |
| | - Generalization-lacking model | normative model |
| | - Delay and table functions | no |
| | - Wider range of application | narrower range of application |
| 2. modeling steps | - Problem conceptualization | problem conceptualization |
| | - Causal diagram<br>- Flow chart | cross impact matrix |
| | - DYNAMO model | DYNAMO model |
| | - Model tests | model tests |
| 3. the system | - Dynamic | dynamic |
| | - Non-linear | linear |
| | - System are bounded | open system |
| | - No limit to variable's value | $0 \leq x_i \leq 1$ |

## The CISD-FORTRAN Program

In order to dilate the application of CISD to nonspecialists who are not familiar with DYNAMO, a FORTRAN program for CISD is compiled. CISD-FORTRAN also produces graphical outputs. A brief scheme is shown in Figure 2.

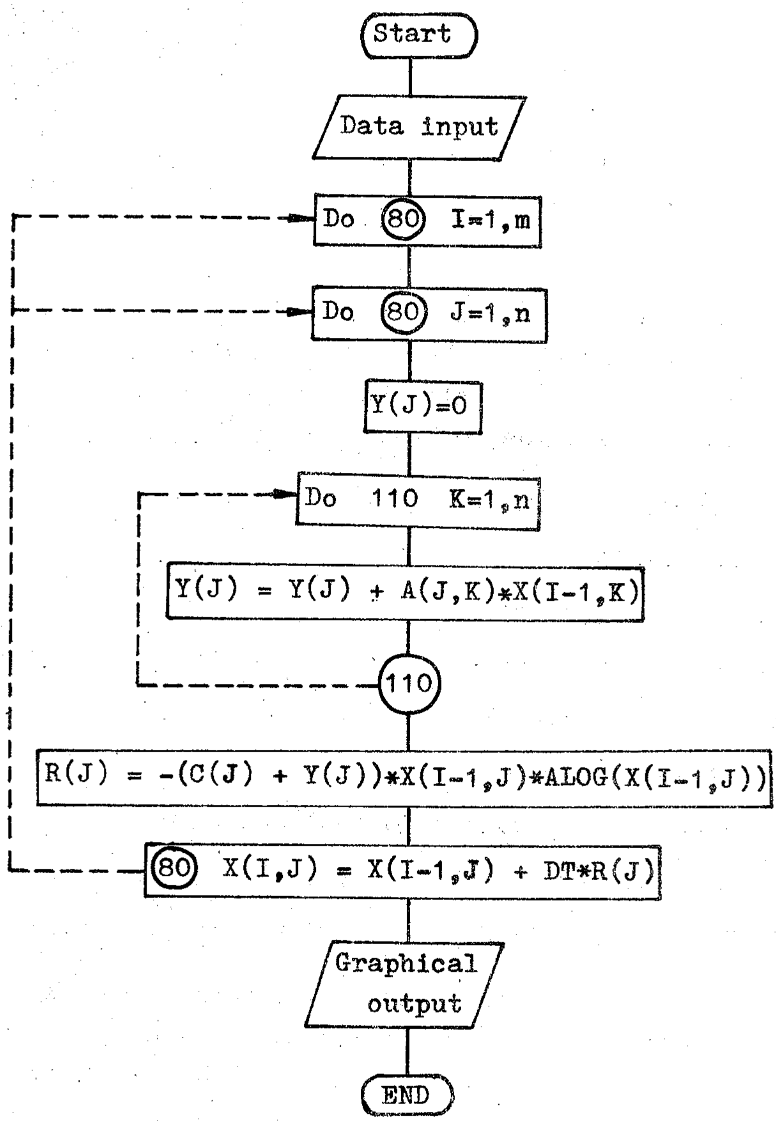


Fig.2 CISD-FORTRAN Program Scheme

## AN EXAMPLE

Agricultural chemicals have played an important historical role in agriculture because they prevent and control the plant diseases, eliminate insect pests. As a result, the agricultural output remains increasing during the past few decades. However, they carry pesticide pollution which makes negative impacts on human health and natural enviornment (e.g., soil, air, water, etc.) at the same time, TA of agricultural chemicals (TAAC) therefore emerges from neccessity. China is the biggist agricultural country with an agricultural population of eight hundred million, it is imperative that we attach great importance to TAAC.

As an example, we coordinate with Zhejiang Research Institute of Chemical Industry to apply CISD to TA of a specific pesticide called Tsumacide, as a result, nine variables are abstracted to describe the impact system as follows:

$x_1$ -- chronic toxicity of the pesticide

$x_2$ -- its acute toxicity

$x_3$ -- the pesticide residue

$x_4$ -- the efficacy of the pesticide

$x_5$ -- the pesticide production

$x_6$ -- the market share

$x_7$ -- pesticide user's attitude towards the pesticide

$x_8$ -- agricultural product consumer's attitude

$x_9$ -- increment of crops and grains

A CIM reflecting the binary interactions of the nine impact variables is obtained through Delphi method and shown in Table 3. Basic runs (one of them shown in Fig. 3) of CISD-TAAC model show that $x_1$ and $x_2$ will increase in a small range over time without outside interventions. If outside policies which prevent

Table 3. CIM of CISD-TAAC

| | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ | $x_6$ | $x_7$ | $x_8$ | $x_9$ |
|---|---|---|---|---|---|---|---|---|---|
| $x_1$ | 0 | +1 | +2 | -1 | +1.5 | 0 | 0 | 0.5 | 0 |
| $x_2$ | 0 | 0 | 0 | -0.5 | +1 | 0 | 0 | 0 | 0 |
| $x_3$ | 0 | 0 | 0 | 0 | +1.5 | +0.5 | 0 | 0 | -0.2 |
| $x_4$ | 0 | 0 | +0.5 | -0.5 | -0.3 | -0.3 | +1 | 0 | 0 |
| $x_5$ | -0.1 | -1 | +0.5* -0.3 | +2 | -1 | -1 | +2 | 0 | +1 |
| $x_6$ | -0.2 | -1 | +0.2 -0.2 | +2 | +1 | -0.5 | +1 | 0 | +0.5 |
| $x_7$ | -0.1 | -2 | +0.5 | +3 | +0.2 | +0.2 | +1 | -0.5 | +2 |
| $x_8$ | -2.5 | -0.5 | -2 | -0.5 | 0 | 0 | 0 | +1 | +1 |
| $x_9$ | 0 | 0 | -0.4 | +2.5 | +0.5 | +0.3 | 0 | 0 | 0 |

* Note that here a CLIP function is used:

$$\mathrm{CLIP(A,B,TIME.K,C)} = \begin{cases} \mathrm{A} & \mathrm{TIME.K} \geq \mathrm{C} \\ \mathrm{B} & \mathrm{TIME.K} < \mathrm{C} \end{cases}$$

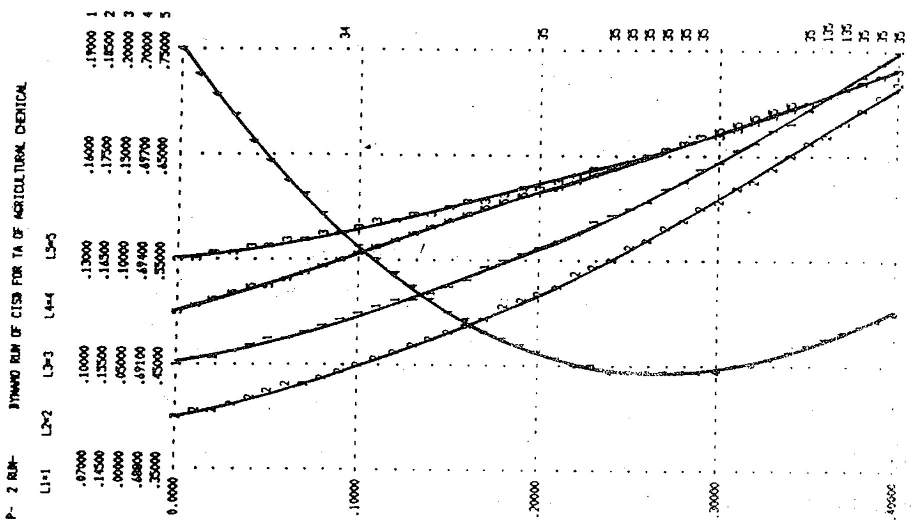

Fig. 3. Basic run of CISD-TAAC

the two kinds of toxicity are added to the model ($c_1$ = -1 and $c_2$ = -1), the curves then decline (shown in Fig. 4). Policies which encourage the pesticide production ($c_5$ = +1) and restrict it ($c_5$ = -1) are tested in the same way. The result shows that the restricting policy is not sensitive to the production, i.e., the demand of the pesticide is decided by the system itself. The encouraging policy promotes the production markedly.

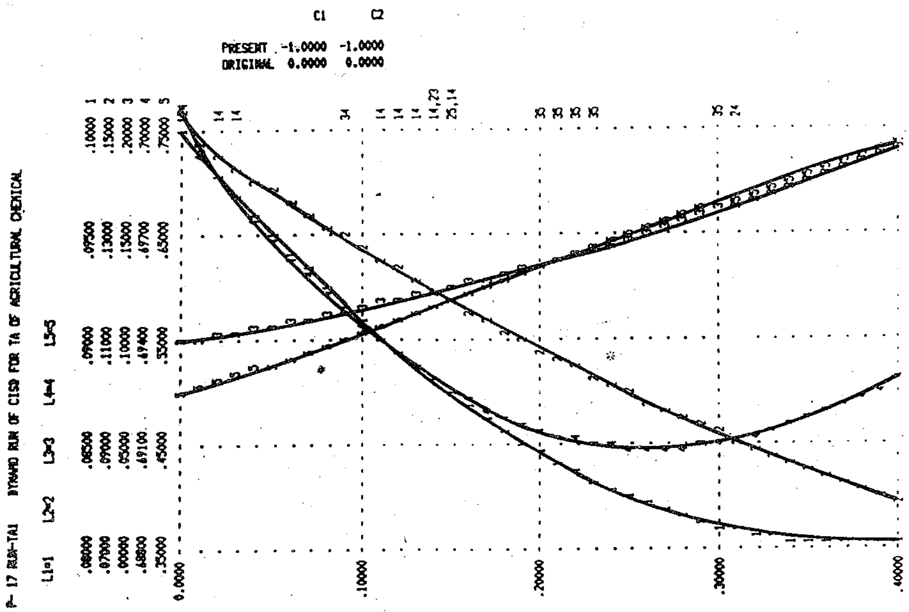


Fig. 4. Changes for rerun of CISD-TAAC

Based on the policy tests, some conclusions and suggestions are reached and submitted in a report to the institute. The brief main points are as follows:

1. Tsumacide is proved to be a pesticide of little toxicity, it can prevent and control plant diseases and pests effectively.
2. Although Tsumacide is slightly poisonous, any toxicity prevented steps can not be neglected.
3. Tsumacide clicks, we suggest that encouraging policies be made for these kinds of pesticides with slight toxicity (e.g., investment prevailing policy).

## CONCLUSIONS

System dynamics seems to be more rapidly developed and more widely used in many fields of research in the past one or two decades. But what is its future? Is there any prospective direction that will lead the way for it?

On one hand, system dynamics, as a methodology, should be established on a very firm basis, it has its own logic and rules, theoretical research on SD itself is therefore emphazisea. On the other hand, it is an applied tool for modeling socioeconomic system, the simpler it is, the more often it can be used.

This paper not merely introduces the CISD procedure, it is more meaningful that it combines two methods together, and a new simplified procedure is born as a result. Could this "marriage" bring us some revelation for our further SD study?

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