A DECISION SUPPORT SYSTEM FOR SYSTEM DYNAMICS MODELING

Pei Weimin, Liu Shu-an and Wang Dingwei

Department of Automatic Control
Northeast University of Technology
Shenyang 110006, China

ABSTRACT

In this study, a decision support system for system dynamics modeling is designed, The intelligent part of the system is composed of a knowledge base, a data base and an inference engine. The function part of the system is composed of some modules for model construction, model generation, model simulation, model interpretation, model management, and PD interface. The proposed system is a production system written in PROLOG, and it can join up with the professional DYNAMO plus software by means of the PD interface. Whole process from modeling to simulation can be realized by the support of the system. An application example is given in this paper.

1. INTRODUCTION

The decision-making of the socioeconomic problem is very diffcult because there are many uncertain quantities and unlinear relations. In order to construct the system dynamics model solving the socioeconomic problem, the modeller who is the system dynamics expert usually need spend a lot of time, and the decision-maker does not intervene in the modeling.

The decision support system (DSS) can directly support the decision-makers to solve unstructured problems by means of man-machine conversation. Total effect yielded by user in combination with computer is better than single effect yielded by user or computer in decision-making. Therefore, the decision support system for system dynamics modeling is useful for the decision-making of the socioeconomic problem.

The proposed system is a decision-faced expert system. The intelligent part of the system is composed of a knowledge base, a data base and an inference engine. The knowledge base stores the expert's modeling knowledge in the form of the rules. The data base stores these facts on the elements(nodes) and causal relations(links) inputed by user and on the types of the variables and couplings gained in the inference. The inference engine gives the inferences and judgments on the basis of the facts and rules. This system is a production system written in PROLOG, and it adopts the way of the forward reference and the strategy of the depth first search.

The function part of the system is composed of some modules for model construction, model generation, model simulation, model interpretation, model management, and PD interface. The system can join up with the professional DYNAMO plus software by means of the PD interface, and whole process from modeling to simulation can be realized continuously by the support of the system.

Brief exacuting processes of the proposed system are;

(1) Extracting the elements (nodes) and causal relations (links) within a problem studied by user.

(2) Composing the causal feedback loops automatically by interconnecting the causal relations and by eliminating inappropriate links.

(3) Transforming the causal-loop diagram into a system flow diagram automatically.

(4) Generating a PD plus simulation program automatically.

(5) Compiling and running the model.

(6) Getting the simulation results.

2. INTELLIGENT PART OF THE SYSTEM

The knowledge base is considered as a library/catalogue of dynamic structures of systems. The causal relations (couplings) is the main input of system dynamics modeling in the proposed system. The data structure of the couplings (links) is given as follows;

Link (INN, TNN, SIGN, TYPE, CT)

where

INN is the name of a cause variable,

TNN is the name of an effect variable,

SIGN is the symbol of a causal action (positive "+" or negative "-"),

TYPE is the type of a causal action (add-mimus type "+ -" or proportion type "× /" ,)

CT is the type of a coupling (material flow "F" or information flow "I").

According to the inputs of the user and facts acquired in teh inference, the data structure of the variables (nodes) is given as follows;

Node (NN, NT, SN, [VAL, EQ, TV])

where

NN is the name of a variable,

NT is the type of a variable,
SN is the abbreviation of a variable,
VAL is the parameter value or initial value,
EQ is a functional expression or equation,
TV is the values of a table function.

The knowledge acquired in system dynamics modeling should be accumulated in the knowledge base, the representation of the knowledge adopts the form of the rules.

The types of the variables and couplings are explained as follows;

X level variable,
R rate variable,
V auxiliary variable,
P parameter,
Y output variable,
D delay variable,
F material flow,
I information flow.

(1) Rules for judging the types of the couplings

Rule 1. If a variable has a cause coupling which is I or F,
then all cause couplings of this variable are I or F.
Rule 2. If a variable has an effect coupling which is I or F,
then all effect couplings of this variable are I or F.
Rule 3. If a cause coupling set of q(i) in link (q(i) , q(j)) is empty,
then the type of Link (q(i), q(j)) is I.
Rule 4. If an effect coupling set of q(j) in Link (q(i) , q(j)) is empty,
then the type of Link (q(i), q(j)) is I.
Rule 5. If the type of Link (q(i), q(j)) is proportion type,
and the type of Link (q(j), q(i)) is add-mimus type,
then the former is I and the latter is F.
Rule 6. If q(i) only has a cause coupling and an effect coupling,
then the types of both couplings are all I.
Rule 7. If q(i) only has a cause coupling which is add-mimus type,
then the type of this coupling is F.
Rule 8. If the cause variable q(i) $\in$ D,
and the effect variable q(j) $\in$ X,
then the cause couplings and effect couplings of q(i) are all F.
Rule 9. If the cause variable q(i) $\in$ D,
and the effect variable q(j) $\in$ X,
then the cause couplings and effect couplings of q(i) are all I.

(2) Rules for judging the types of the variables

Rule 10. If the effect coupling set of the variable q(i) is empty, then q(i) ∈ Y.

Rule 11. If the cause α coupling set of the variable q(i)is empty,
then q(i) ∈ P.

Rule 12. If the cause coupling set of the variable q(i) is F,
and the effect coupling set of the variable q(i) is I,
then q(i) ∈ X.

Rule 13. If the cause coupling set of the variable q(i) is I,
and the effect coupling set of the variable q(i) is F,
then q(i) ∈ R.

Rule 14. If the cause couplings and effect couplings of the variable q(i) are all I,
then q(i) ∈ V.

(3) Rules for generating the DYNAMO equations

Rule 15. If NT= "X" ,
then the equation is
L SN.K=EQ
N SN=VAL.

Rule 16. If NT= "R" ,
then the equation is
R SN.KL=EQ.

Rule 17. If NT= "D" ,
and it is the material delay,
then the equation is
R SN.KL=EQ
N SN=VAL.

Rule 18. If NT= "D" ,
and it is the information delay,
then the equation is
A SN.K=EQ
N SN=VAL.

Rule 19. If NT= "V" or "Y" ,
and TV has no values,
then the equation is
A SN.K=EQ.

Rule 20. If NT= "V" or "Y" ,
and TV has values,
then the equation is
A SN.K=EQ
T values of table function=TV.

Rule 21. If NT= "P" ,
and EQ has values,
then the equation is
A SN.K=EQ

Rule 22. If NT= "P" ,
and EQ has no values,
then the equation is

C SN=VAL.

3. FUNCTION PART OF THE SYSTEM

The function part of the proposed system is made up of the following function modules:

1) Model construction module
This module is useful to construct the feedback structure of the model.
(1) Inputting the goal of the model.
(2) Extracting the causal relations and variables.
(3) Composing the causal feedback loops.

2) Model generation module
This module is useful to transform the causal-loop diagram into a system flow diagram.
(1) Determining the type of the variable.
(2) Extracting the abbreviation of the variable.
(3) Giving the initial condition.
(4) Generating the simulation program.

3) Model simulation module
This module is useful to realize the run and output of the model.
(1) Modifying the model.
(2) Compiling the model.
(3) Running the model.
(4) Getting the output of simulation.
(5) Inquiring the error information.

4) Model interpretation module
This module is useful to inguire relevant information.
(1) Inguiring the name and abbreviation of the variable.
(2) Inguiring the variable set and couple set.
(3) Inguiring the variable type set.
(4) Inguiring the causal feedback looes.
(5) Inguiring the somulation eguations and initial conditions.

5) Model management module
This module is useful to realige the management of the models.
(1) Naming the model.
(2) Calling the model.
(3) Storing the model.
(4) Displaying the model.
(5) Sparing the model.
(6) Changing the name of the model.
(7) Deleting the model.
(8) Combining the models.

6) PD interface module
This module is useful to realize man-machine conversation. The proposed system can directly with the professional DYNAMO plus software by means of the PD interface.

As a result of the support of the DSS, only user inputs the goals, elements and causal relations within a system problem, the computer can compose the DYNAMO model and run the model with multiple schemes, at last generate the report file. Not only that, but also user can modify the model to improve the decision-making by means of man-machine conversation. The functions of above mentioned modules can be further expanded in accordance with the needs of the users.

4. Application Example

A retail store medel as an application example is provided to verify the applicability of the proposed system. The names of the variables in this model are explained as follows;

DFLORD	Delay Filling Orders
DSUNV	Desired Inventory
ORDERS	Orders Received
INV	Inventory
SHIP	Shipments Sent
UFLORD	Unfilled Orders
PRCORD	Purchase Orders
INVCOV	Inventory Coverage
IVADTM	Inventory Adjustment Time
SHPRCD	Shipments Received
SMSLS	Smoothed Sales

The information about the work of the DSS is outlined below.

SYMBOL NAME --- NODE NAME

```
--------------------------------------------------------------------------------
                        VDFLORD <<--------------------->> DFLORD
                         VDSINV <<--------------------->> DSINV
                        RORDERS <<--------------------->> ORDERS
                           XINV <<--------------------->> INV
                          RSHIP <<--------------------->> SHIP
                        XUFLORD <<--------------------->> UFLORD
                        RPRCORD <<--------------------->> PRCORD
                        PINVCOV <<--------------------->> INVCOV
                        PIVADTM <<--------------------->> IVADTM
                        DSHPRCD <<--------------------->> SHPRCD
                         DSMSLS <<--------------------->> SMSLS
--------------------------------------------------------------------------------
```

SET OF SYSTEM NODES

```
------------------------------------------------------------------------------
       DFLORD                  DSINV                   ORDERS
       INV                     SHIP                    UFLORD
       PRCORD                  INVCOV                  IVADTM
       SHPRCD                  SMSLS
                      ---------* Total     11     nodes *---------
------------------------------------------------------------------------------
```

SET OF SYSTEM LINKS

```
------------------------------------------------------------------------------
   ORDERS -- ( +, */ ) -> SMSLS             DFLORD -- ( -, */ ) -> SHIP
   UFLORD -- ( +, */ ) -> SHIP              ORDERS -- ( +, +- ) -> UFLORD
     SHIP -- ( -, +- ) -> UFLORD              SHIP -- ( -, +- ) -> INV
    DSINV -- ( +, +- ) -> PRCORD             SMSLS -- ( +, */ ) -> DFLORD
      INV -- ( -, */ ) -> DFLORD               INV -- ( -, +- ) -> PRCORD
   IVADTM -- ( -, */ ) -> PRCORD             SMSLS -- ( +, +- ) -> PRCORD
   INVCOV -- ( +, */ ) -> DSINV             SHPRCD -- ( +, +- ) -> INV
   PRCORD -- ( +, */ ) -> SHPRCD            SMSLS -- ( +, */ ) -> DSINV
                      ---------* Total 16 Links *---------
------------------------------------------------------------------------------
```

LINKS OF NODES

```
------------------------------------------------------------------------------
      INV -- ( -, */ ) -> DFLORD            DFLORD -- ( -, */ ) -> SHIP
    SMSLS -- ( +, */ ) -> DFLORD
-----   -----*-----  -----*-----  -----*-----  -----*-----  -----*-----   -----
   INVCOV -- ( +, */ ) -> DSINV              DSINV -- ( +, +- ) -> PRCORD
    SMSLS -- ( +, */ ) -> DSINV
-----   -----*-----  -----*-----  -----*-----  -----*-----  -----*-----   -----
                                            ORDERS -- ( +, */ ) -> SMSLS
                                            ORDERS -- ( +, +- ) -> UFLORD
-----   -----*-----  -----*-----  -----*-----  -----*-----  -----*-----   -----
     SHIP -- ( -, +- ) -> INV                  INV -- ( -, */ ) -> DFLORD
   SHPRCD -- ( +, +- ) -> INV                  INV -- ( -, +- ) -> PRCORD
-----   -----*-----  -----*-----  -----*-----  -----*-----  -----*-----   -----
   UFLORD -- ( +, */ ) -> SHIP                SHIP -- ( -, +- ) -> INV
   DFLORD -- ( -, */ ) -> SHIP                SHIP -- ( -, +- ) -> UFLORD
-----   -----*-----  -----*-----  -----*-----  -----*-----  -----*-----   -----
   ORDERS -- ( +, +- ) -> UFLORD            UFLORD -- ( +, */ ) -> SHIP
     SHIP -- ( -, +- ) -> UFLORD
-----   -----*-----  -----*-----  -----*-----  -----*-----  -----*-----   -----
   IVADTM -- ( -, */ ) -> PRCORD            PRCORD -- ( +, */ ) -> SHPRCD
```

```
     SMSLS -- ( +, +- ) -> PRCORD
     DSINV -- ( +, +- ) -> PRCORD
       INV __ ( -, +- ) -> PRCORD
-----   -----*-----  -----*-----  -----*-----  -----*-----  -----*-----   -----
                                         INVCOV -- ( -, */ ) -> DSINV
-----   -----*-----  -----*-----  -----*-----  -----*-----  -----*-----   -----
                                         IVADTM -- ( -, */ ) -> PRCORD
-----   -----*-----  -----*-----  -----*-----  -----*-----  -----*-----   -----
   PRCORD -- ( +, */ ) -> SHPRCD         SHPRCD -- ( +, +- ) -> INV
-----   -----*-----  -----*-----  -----*-----  -----*-----  -----*-----   -----
   ORDERS -- ( +, */ ) -> SMSLS           SMSLS -- ( +, +- ) -> PRCORD
                                          SMSLS -- ( +, */ ) -> DSINV
                                          SMSLS -- ( +, */ ) -> DFLORD
-------------------------------------------------------------------------------
```

TYPE OF VARIABLES

```
-------------------------------------------------------------------------------
                                Set of < X >
                                ----------
     INV                     UFLORD
      ----------------------* Total      2 nodes  *---------------------------
                                Set of < R >
                                ------------
     ORDERS                  SHIP                  PRCORD
      ----------------------* Total      3 nodes  *---------------------------
                                Set of < V >
                                ------------
     DFLORD                  DSINV
      ----------------------* Total      2 nodes  *---------------------------
                                Set of < Y >
                                ------------
      ----------------------* Total      0 nodes  *---------------------------
                                Set of < P >
                                ------------
     INVCOV                  IVADTM
      ----------------------* Total      2 nodes  *---------------------------
                                Set pf < D >
                                ------------
     SHPRCD                  SMSLS
      ----------------------* Total      2 nodes  *---------------------------
-------------------------------------------------------------------------------
```

TYPE OF COUPLINGS

```
-------------------------------------------------------------------------------
                     material couplings < F >
```

```
SHIP -- (-,+-) -> INV                SHIP -- (-,+-) -> UFLORD
ORDERS -- (+,+-) -> UFLORD           PRCORD -- (+,*/) -> SHPRCD
SHPRCD -- (+,+-) -> INV              ORDERS -- (+,*/) -> SMSLS
              -------* Total   6 links *-------
---------*----------*-----------*-----------*-----------*-----------*-----
```

information couplings < I >

```
INV -- (-,*/) -> DFLORD              DFLORD -- (-,*/) -> SHIP
UFLORD -- (+,*/) -> SHIP             INV -- (-,+-) -> PRCORD
DSINV -- (+,+-) -> PRCORD            INVCOV -- (+,*/) -> DSINV
IVADTM -- (-,*/) -> PRCORD           SMSLS -- (+,*/) -> DFLORD
SMSLS -- (+,*/) -> DSINV             SMSLS -- (+,+-) -> PRCORD
              ----------* Total   10 Links *----------
```

CAUSAL - RELATIONSHIP LOOPS

```
PRCORD      ---- (+) ->   SHPRCD     ---- (+) ->   INV    ---- (-) ->
PRCORD
  ------------ Negative feedback loop, including  3 nodes. ------------
-----  -----*-----  -----*-----  -----*-----  -----*-----  -----*-----
INV     ---- (-) ->  DFLORD      ----- (-) ->  SHIP   ---- (-) ->
INV
  -------- Negative feedback loop, include     3 nodes.---------
-----  -----*-----  -----*-----  -----*-----  -----*-----  -----*-----  ----
SHIP    ---- (-) ->  UFLORD      ----- (+) ->  SHIP
  -------- Negative feedback loop, including   2 nodes.---------
               -------- * Total       3 loops * --------
```

INITIAL CONDITIONS

Specification,

NS-SEED	0.1	+271
TIME	1	+271
DT	1	+271
LENGTH	20	+271
SAVPER	0	+271
ABS-EER	0	+271
REL-ERR	0	+271
CMP-N-1	0	+271

```
Parameter value;
Initial value of state or delay;
        XINV ----->
     XUFLORD ----->
     DSHPRCE -----> delay3(prcord. jk, dlrcgd)
      DSMSLS -----> smooth(orders. jk, dsmord)
Function;
     DSHPRCD -----> DELAY3(proord. jk, dlrcgd)
      DSMSLS -----> SMOOTH(orders. jk, dsmord)

Table function;
```

SIMULATION PROGRAM

```
*  ---   LSSD.DYN   ---  *
L  XINU.K=XINV.J+DT*(-RSHIP.JK+DSHPRCD.JK)
N     XINV=vdsinv
R  RSHIP.KL=XUFLORD.K*(1/VDFLORD.K)
A  VDFLORD.K=TABLE(TDFLORD, xinv.k/dsmsls.k,4,12,4)
T     TDFLORD=1.5,1,.75
A  DSMSLS.K=SMOOTH(rorders.kl,8)
R  RORDERS.KL=bsord+step(stpord,5)
C  bsord=100
C  stpord=100
R  DSHPRCD.KL=DELAY3(rprcord.kl,dlrcgd)
N     dlrcgd=6
R  RPRCORD.KL=DSMSLS.K+(VDSINV.K-XINV.K)/PIVADTM
C     PIVADTM=4
A  VDSINV.K=DSMSLS.K*PINVCOV
C     PINVCOV=8
L  XUFLORD.K=XUFLORD.J+DT*(RORDERS.JK-PSHIP.JK)
N     XUFLORD=vdflord*rorders
N     TIME=1
SAVE  DSHPRCD,XINV,VDFLORD,RPRCORD,VDSINV,RSHIP,XUFLORD,DSMSLS,RORDERS,PIVADTM,
      PINVCOV
SPEC   CMP_N_1=.1,NS_SEED=0.1,DT=1,LENGTH=60,SAVPER=1,ABS_ERR=0,REL_ERR=0
```

PRINTED OUTPUT

TIME	1.	5.	9.	13.	17.	21.	25.
PINVCOV	8.	8.	8.	8.	8.	8.	8.
PIVADTM	4.	4.	4.	4.	4.	4.	4.
DSHPRCD	100.	100.	104.69	206.16	347.13	395.72	314.12

DSMSLS	100.	100.	141.38	165.64	179.86	188.19	193.08
RORDERS	100.	200.	200.	200.	200.	200.	200.
RPRCORD	100.	100.	281.76	413.17	394.02	252.42	112.86
RSHIP	100.	100.	180.11	199.74	200.	223.99	208.37
VDFLORD	1.	1.	1.4965	1.5	1.5	1.1706	.89614
VDSINV	800.	800.	1131.1	1325.1	1438.9	1505.5	1544.6
XINV	800.	800.	569.53	335.	582.23	1248.6	1865.5
XUFLORD	100.	100.	269.53	299.61	300.	262.21	186.72

TIME	29.	33.	37.	41.	45.	49.	53.	57.
PINVCOV	8.	8.	8.	8.	8.	8.	8.	8.
PIVADTM	4.	4.	4.	4.	4.	4.	4.	4.
DSHPRCD	181.35	91.676	99.675	182.1	263.29	284.75	243.26	179.25
DSMSLS	195.94	197.62	198.61	199.18	199.52	199.72	199.84	199.9
RORDERS	200.	200.	200.	200.	200.	200.	200.	200.
RPRCORD	62.173	123.5	232.64	297.13	281.5	212.72	146.91	130.01
RSHIP	200.02	194.18	187.74	195.17	205.11	209.99	203.35	199.54
VDFLORD	.82933	.90623	1.0857	1.2459	1.2054	1.0325	.93379	.91259
VDSINU	1567.5	1581.	1588.8	1593.5	1596.2	1597.8	1598.7	1599.2
XINU	2102.6	1877.5	1452.7	1201.7	1268.2	1545.8	1810.4	1878.8
XUFLORD	165.89	175.97	203.83	243.16	247.24	216.83	189.89	182.1

5. CONCLUSIONS

In this study, a decision support system for system dynamics modeling is designed. The proposed system has effective intelligent part and function part. The system can join up with the PD plus software to realige the modeling and simulation. Due to the system only need input the causal relations as elementary condition of the modeling, so user is easy to use it. The results of the preliminary applications have proveded that the DSS is a powerful tool for the decision-making of the socioeconomic problems.

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