PACKAGED SYSTEM DYNAMICS MODELS

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ABSTRACT

One constraint on the growth of System Dynamics as a methodology can be removed by enabling non-professional users to make use of System Dynamics models with reduced professional involvement. Such use requires that models be disseminated in packaged form, that is, with supplementary software that gives English-language access to the model, guides the user in its intelligent use, and performs automatic analysis of simulation results. A new generation of the DYNAMO simulation language contains tools that assist the model builder in the packaging process. Experience has shown that while the benefits of packaging are considerable, it is easy to underestimate the effort involved.

Since the late 1950s, System Dynamics modeling has proven to be a powerful means of addressing some of society's most complex systems and problems. However, direct access to powerful DYNAMO models and to many of the benefits of System Dynamics has been available only to career professionals. In order to gain this access, each professional System Dynamicist invested many years in learning how to use computers, the DYNAMO language, and how to apply the System Dynamics modeling methodology.

Through the years, many of the modeling efforts of this small group of professionals have been sponsored (directly or indirectly) by managers of corporate and government entities. The involvement of these decision-makers has stemmed from their belief in the power and applicability of System Dynamics modeling, yet very few of them have been willing or able to acquire the skills to practice System Dynamics themselves. As a result, managers have relied on System Dynamics professionals to construct models, perform simulations, and interpret the results. The System Dynamics professional has been the interface between the model and its ultimate beneficiary, the decision-maker.

The authors of this paper feel that the need for a "human interface" has been, and will continue to be, a constraint on the growth and acceptance of System Dynamics. There are no more than a few hundred qualified professionals worldwide, and the rate of addition of new professionals is low. If the need for this constant human link between the model user (the manager or decision-maker) and the modeling professional could somehow be reduced, the benefits might be felt on two fronts: use of models by real decision-makers might increase substantially, and scarce, valuable modeling professionals could devote more attention to the things only they can do.

In order to reduce the non-professional model-user's need for a human

interface, we must provide:
- some means of allowing the user access to those model parameters and policy levers that are appropriate, and restricting access to those that are not;
- guidance for the user in selecting and modifying model parameters and policy levers in ways appropriate to his situation;
- models that behave well for all reasonable values of those parameters and policy levers over which the user can exercise control;
- displays of simulation outputs that can be quickly and easily understood by the non-professional user;
- automatic analysis of simulation results, so that the causes of behavioral differences between simulations are readily apparent to the non-professional user.

For the past two years Pugh-Roberts Associates, Inc., has been developing such systems on a custom basis for its consulting clients. These efforts, though still in their early stages, have already resulted in much learning and in vastly improved second-generation systems, with even greater advances now on the horizon. The intent has been to enable intelligent, powerful use of System Dynamics models by managers and decision-makers who have no detailed knowledge of the DYNAMO language or of the System Dynamics modeling methodology. The requirements listed above have been satisfied largely by means of new software routines that are distinct but not separate from the simulation model being used. The result is more than just a model; it is a package of software routines with a model at its core -- a packaged model.

In 1984, The Software Group at Pugh-Roberts began development of a new generation of the DYNAMO language, intended to provide a platform for continued advances in DYNAMO simulation capability over the next decade. A decision was made to incorporate in this new generation standardized and improved versions of the model-packaging software inspired by Pugh-Roberts' consulting clients. The PROFESSIONAL DYNAMO system is the result, and two of its five modules are aimed squarely at assisting professional model-builders in the task of putting DYNAMO models into the hands of non-professional users. These modules are the Executive Interface and the Report Generator.

THE PROFESSIONAL DYNAMO EXECUTIVE INTERFACE

The Executive Interface Module provides the means to satisfy the first two requirements for intelligent non-professional model use:
- a way of allowing the user access to those model parameters and policy levers that are appropriate, and restricting access to those that are not;
- guidance for the user in selecting and modifying appropriate model parameters and policy levers.

The Executive Interface enables the model builder to construct a tree-like structure of English-language menus and prompts to guide model users through the appropriate sectors of the model. Depending on what the model builder includes in the Input File (see Figure 1), the user can

study the purpose and scope of various model sectors, review current parameter values, modify parameter and policy-switch values, and choose from a selection of reports, graphs, and plots. The model builder can also allow users to choose between alternative equation structures for various sectors of the model. The Input File contains instructions (created by the model builder) to the Executive Interface Module to display text and parameter values to the user, to accept his responses where appropriate, and to place his rerun instructions into the Rerun File and his report instructions into the Report Specification File. The Rerun File is read by the DYNAMO Run Module and is the basis for a single simulation run of the model. The Report Specification File is read by the Report Generator Module and is the basis for creating system outputs (See Figure 1).
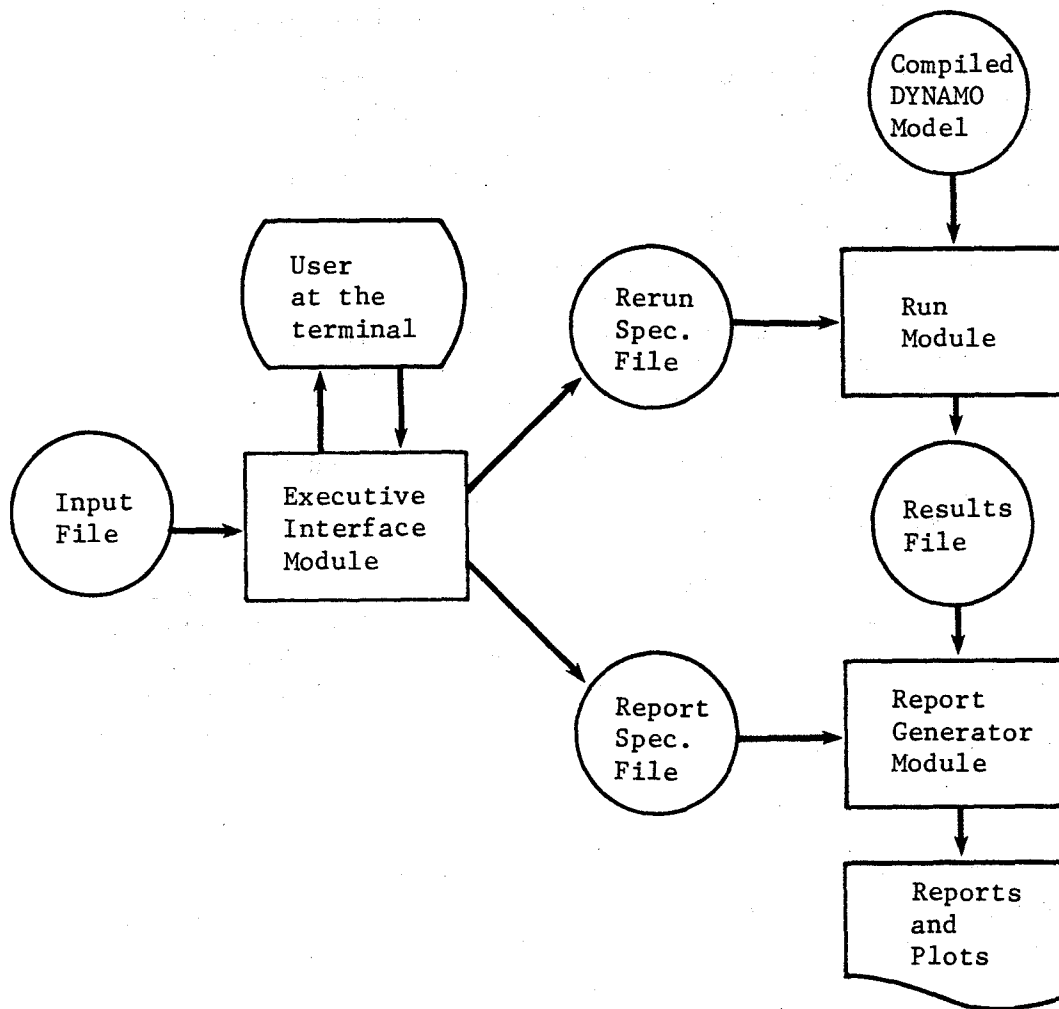
Figure 1

THE PROFESSIONAL DYNAMO REPORT GENERATOR

The Report Generator Module provides the means to satisfy the last two requirements for intelligent non-professional model use:
- displays of simulation results that can be quickly and easily understood by the user;

- automatic analysis of simulation results, so that the
  causes of behavioral differences between simulations are
  readily apparent to the user.

The Report Generator Module represents a major upgrade of DYNAMO's
traditional output capabilities, a necessity if System Dynamics models
are to be put into the hands of non-professional users. Managers and
decision-makers should not have to decipher seven-character neumonic
variable names in order to understand model output. Neither should they
be expected to sort through output that has not changed (from the
previous model simulation) in order to find those variables that have
changed. Moreover, non-professional users often need to array and view
data in standard formats such as balance sheets and income statements.

In order to meet these requirements, the Report Generator Module has the
following features (in addition to traditional DYNAMO print and plot
formats):
  - the model builder has complete freedom to define what
    information a report will contain and where it will
    appear in the report.
  - It's easy to mix text, data, and business graphics in a
    single report.
  - The Report Generator contains arithmetic operators which
    allow the model builder to include in reports the
    results of computations performed outside the model.
  - The Report Generator contains logical operators, which
    enable the model builder to construct "smart" reports
    that appear only when some pre-specified condition is
    attained.
  - The Report Generator is capable of preserving the results
    of past simulations, and of combining results from
    multiple simulations in a single pre-defined report.

The Report Generator Module reads the Report Specification File gener-
ated by the Executive Interface Module, and the Results File written by
the DYNAMO Run Module. It uses the data in these files in creating the
reports and plots defined in advance by the model builder, and selected
by the user.

A PACKAGED MODEL EXAMPLE

In order to illustrate the characteristics of a packaged model, the
authors have constructed an example using the Simple Retail Sector model
found in the DYNAMO User's Manual. Figures 2-8 are examples of what the
user might see from the Executive Interface, and Figure 9 illustrates
some of the Report Generator's capabilities.

```
SIMPLE RETAIL SECTOR MODEL

Please select one of the following by typing
the  number  of  your  choice,  followed  by  a
carriage return.

    1) Operating Instructions for this
       session
    2) Exploring the Retail System
    3) Exit from this session
```

Figure 2

If the user chooses item number two, he'll see the following screens.

```
SIMPLE RETAIL SECTOR MODEL

This  model  includes  a  retail  outlet  that
orders goods from a distributor and sells them
to its customers.

Please type a carriage return to view the next
screen.
```

Figure 3

```
EXPLORING THE SIMPLE RETAIL SYSTEM

The  Retail  System  has  two  main  sectors.
Please indicate which sector(s) you'd like to
explore.

    1) Customer orders to the Retailer
    2) The flow of goods through the
       system
    3) Neither of the above
```

Figure 4

If the user selects item 1, he'll see the following screens.


```
CUSTOMER ORDERS TO THE RETAILER

The backlog of unfilled customer orders is a
level, augmented by the customer order rate
and  depleted  by  the  rate  of  shipment  to
customers.    The  simulation  begins  with  a
constant stream of weekly orders, and an equal
rate of shipments to customers.

Please type a carriage return to see the next
screen.
```

Figure 5

CUSTOMER ORDERS TO THE RETAILER

Five weeks into the simulation, the model is
"shocked" by a sudden increase in the customer
order rate.   Please indicate which customer
order parameter(s) you'd like to examine and
perhaps modify.

    1) The initial weekly customer order
       rate
    2) The size of the order-rate shock
    3) Neither of the above

Figure 6

If the user elects item 1, he'll see the following screen.

INITIAL WEEKLY CUSTOMER ORDER RATE

The initial number of customer orders per week
is:
    1000

Please type a new number for the initial order
rate, or a carriage return to use the above
value.

Figure 7

If the user chooses both items 1 and 2 in Figure 4, the Executive
Interface will let him explore the flow of goods through the system, and
offer an appropriate choice of parameter changes. In this way the
Executive Interface conducts the user down each branch of the tree-like
structure that he has chosen to investigate. When the last such branch
has been explored and the appropriate parameters altered, the Interface
might invite the user to run the model with the revised parameters, or to
save the revised parameters without a model run (In either case the Input
File could be set up to prompt the user for a name for the rerun file
created). If the user elects to run the model, he might now be prompted
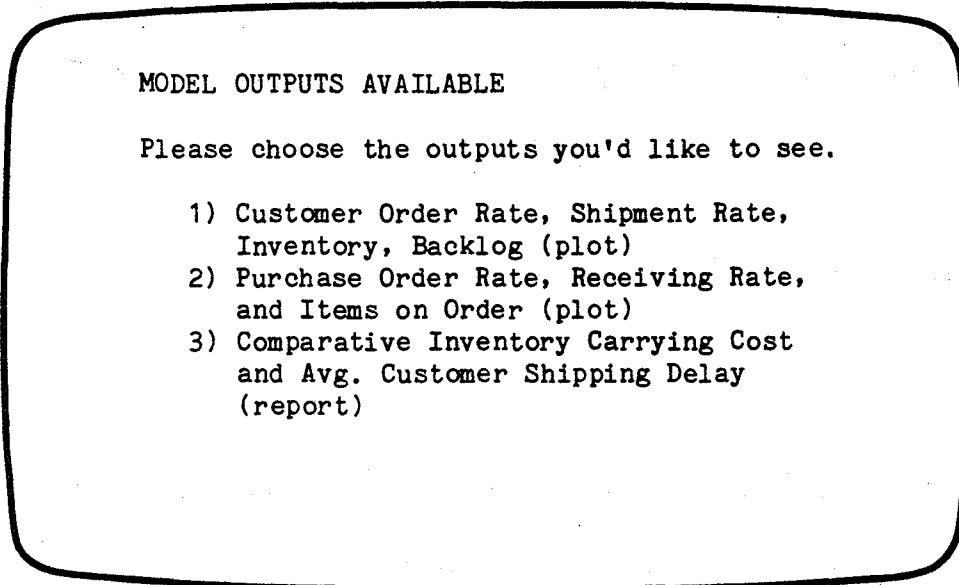for his choice of model outputs, as shown in Figure 8.

MODEL OUTPUTS AVAILABLE

Please choose the outputs you'd like to see.

    1) Customer Order Rate, Shipment Rate,
       Inventory, Backlog (plot)
    2) Purchase Order Rate, Receiving Rate,
       and Items on Order (plot)
    3) Comparative Inventory Carrying Cost
       and Avg. Customer Shipping Delay
       (report)

Figure 8

Items 1 and 2 from the above menu would involve traditional DYNAMO plots,
but item three is new, as shown in Figure 9.

```
COMPARATIVE INVENTORY CARRYING COST, AVERAGE
CUSTOMER SHIPPING DELAY

                              Simulation

                        A       C       D

Carrying Cost          110     137      96

Shipping Delay,         14      12      19
  average, days
```

Figure 9

Figure 9 illustrates a number of the new output capabilities needed to put System Dynamics models into the hands of non-professional users. The carrying costs and average shipping delays can be calculated by the Report Generator Module, outside of the DYNAMO model. Data for these calculations would be drawn from the Results File (see Figure 1). The Report Generator would access the appropriate data for each of several past runs, perform the specified calculations, and print the results. Using both the logical and arithmetic operators, the model builder could define the Comparative Report so that any run with results that differ from the current run by less than a specified amount will not appear, or so that line items built into the predefined report will not appear unless they represent a significant change from a base run. In addition to DYNAMO prints and plots, and custom reports, the Report Generator will also be capable of producing a complete range of business graphics, including bar and pie charts, and X-Y plots.

THE COSTS OF PACKAGING A MODEL

There is a great temptation to assume that, once the core model is
"complete", packaging for non-professional users will require only a
modest fraction of the time involved in creating, testing, and debugging
the model itself. Pugh-Roberts' experience over the last two years has
shown that the real cost of packaging can easily match the cost of the
original model development effort. In some cases packaging can cost
significantly more than the original model. Breaking the model into
small chunks for successive packaging can be a very useful discipline,
both to control "cathedral-building" and to force the setting of
priorities to ensure that the most important parts will be packaged
first.

The major tasks associated with packaging a model are:
- installing "hooks" in the model as required by the
  parameters and policy levers to which the user will
  have access;
- testing model behavior over the entire range of values
  for parameters to which the user will have access;
- developing the Executive Interface File that will
  constitute the "front end" of the packaged model;
- developing the Report Specification File that consti-
  tutes the "back end" of the packaged model.

The need for testing may not be obvious, since most professionals already
test their models for robust behavior under extreme condi- tions.
Professionals, however, employ an expert's definition of extreme
conditions, which is based in part on an intimate knowledge of the model,
and often on a narrow definition of model scope and purpose. The
non-professional user can come up with some incredibly extreme conditions
because he lacks detailed knowledge of the model, and because
non-professional users, as a group, may well attempt to apply the model
more broadly than would the professional user. The model builder should
thoroughly acquaint himself with the broader needs of the
non-professional user, and adapt the model to meet those needs where
appropriate.

The Report Specifications may also require substantially more time than
anticipated, if the needs of the non-professional are to be fully met.
Often, the reports that prove more than adequate for a professional's
analysis and understanding of model results are sufficient only to raise
questions in the mind of a non-professional. The non-professional user
almost always requires one or more additional layers of explanatory
reports. In other words, the report structure should be designed so that
when the user looks at a report and asks "Why? What caused it to behave
that way?" there is another level of explanatory detail to which he can
turn. Achieving such a report structure can require several successive
design-development-test cycles.

On the positive side, substantial benefits can be derived from packaging
System Dynamics models.

- Done well, it can result in a better model than might
  have emerged without packaging. This is because
  development of a really successful packaged model
  requires a more fundamental understanding of the end
  user's situation, needs, and mental processes than if a
  "human interface" is to be employed.
- Packaging and the non-professional use that it enables
  give users an feeling of "ownership" and confidence in
  the model, important factors in its continued use and
  significant aids to building long-term relationships
  with model users.
- Packaging removes much of the "black box" appearance of
  unpackaged System Dynamics models and can substantially
  enhance the model's credibility in the eyes of the
  non-professional user. This may be counterintuitive to
  the professional modeler, for whom the additional
  software associated with packaging obscures, rather
  than illuminates the model. But for the non-
  professional, seeing "the computer" prompt him
  intelligently in English, and seeing detailed and
  thoughtfully-designed model outputs report   realistic
  model behavior often seems to convert even the most
  skeptical managers.
- Although it requires a somewhat different package than
  would be created for a non-professional user, packaging
  a model can be a surprisingly effective way to enhance
  the productivity of model builders during the model
  test and policy design stages. If the framework for a
  non-professional package is set up early in the
  modeling process, modifying its content for
  professional use entails a relatively minor cost,
  especially when compared to the benefits derived from a
  package aimed at professional analyses.
- Finally there are the original arguments for packaging
  models. High-quality packaging should make models
  accessible to a much broader group of users. This
  should free the professional from some of the current
  need to stand between the user and his model, and
  should enable him to focus more on creating, packaging,
  and disseminating new models.