MODELING A WEATHER ENVIRONMENT

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ABSTRACT

The need to model environmental effects arises frequently as the depth and coverage of simulation studies increase. Many military and commercial operations are in some way affected by weather conditions. The addition of weather effects modeling enhances simulation studies of these kinds of operations. Weather and weather effects models have been successfully utilized in several recent simulation studies conducted by Convair division of General Dynamics.

A mathematical formulation of weather conditions, the construction of two distinct kinds of weather models, the construction of a predictive mechanism, and the implementation of these concepts in GPSS/360 are presented.

MODELING A WEATHER ENVIRONMENT

The need to model environmental effects arises frequently as the depth and coverage of simulation studies increase. Many military activities such as naval supply systems, air tactical operations, and land force movements are affected to some degree by weather. Commercial enterprises such as airport operations, lumber industry operations, off-shore oil well operations, and water supply systems are also strongly affected by weather conditions. Simulation studies of such systems are enhanced by the addition of weather effects modeling. Weather and weather effects models have been successfully utilized in several recent simulation studies conducted by Convair division of General Dynamics.

The capability for efficiently and easily modeling an environment and for integrating it into an "operations system" model is provided by the methods described in this paper. The models developed to date have been directed primarily toward an analysis of the operations aspects of a complex system where the weather directly affects the operational decisions made. Thus, the outcome of the model and the results of the simulation study are also affected.

Simulation of Weather

The scope and the level of detail of the weather modeling required will depend on the system being simulated and on the sensitivity of the system to the weather. General weather patterns over an extensive area may be all that one model requires, while another may require very detailed information about the weather at a particular location. Still another may require only daily knowledge of the weather, while minute by minute knowledge is required elsewhere. These differences in scope of modeling and degree of detail will result in different forms of weather models.

The one significant aspect of weather relating to the system under study is modeled, rather than multiple weather effects being modeled in a more elaborate manner. Weather is a very complex phenomenon to understand, let alone to model. For this reason, when modeling the weather, only one facet is considered at a time. This formulation of the weather as one condition independent of other aspects of weather does not provide insight into how weather behaves, but it does provide an environmental background of sufficient accuracy for the simulation study.

It becomes easier to communicate about the modeling process if two models are referred to:

1. The primary model which is the system without any weather.
2. The background model which is the weather model.

As an example, if the primary model includes ship movement upon an ocean, the background model would employ sea heights as this is the major weather component affecting the system. The sea height is modeled in and of itself without consideration of interactions such as wind effect upon wave action. The weather model is constructed for the resultant aspect of weather that is most significant in terms of the primary model's requirements.

The facet of weather that is being modeled can be described in terms of some or all of these four characteristics:

1. The weather condition at a particular time and location.
2. The change in condition over time at a fixed location.

3. The change in condition with a change in location at a fixed time.

4. The change in condition with both temporal and locational changes.

Wind, cloud cover, visibility, precipitation, temperature, or whatever the weather condition — the weather can be described by its present and future values at fixed or changing locations. These characteristics expressing weather conditions are basic to the modeling methods that follow.

Changes in the weather with changes in time (location) are modeled at discrete points in time (location). This is expedient since most simulation languages use a discrete timing interval. Modeling weather as a discontinuous process is satisfactory providing the primary model has accurate information at the times (locations) required, and that the value of the weather at intervening times (locations) is not relevant to the primary model.

When considering temporal changes in weather it is necessary to reference the changes to a specific observation interval, that is, the time between successive observations. (It is assumed that continuous observations are not employed.) This is required due to the pronounced difference in the effects observed when the observations are made at different intervals. An example should help to clarify this point. Of interest are cloud conditions over a particular location. With an observation interval of less than an hour the continuation of a particular cloud or hole is important. If the interval is greater, on the order of days, then the change in the general cloud cover is important. For a still greater interval, seasonal variations become pertinent. Thus, three different perspectives of the same phenomenon result from the difference in the observation interval.

The second dimension of weather variation comes with locational change. The spatial framework of the weather can be considered in various ways. As with the temporal framework, simplification and stratification are expedient. If weather at a single location is required by the primary model, the spatial framework is trivial. If required at multiple locations, the simplest approach is to assume independence over space and form a set of models with each location having its own weather model. However, if the weather is required along a path, this may not give enough consistency to the set of models. The weather at a location can be assumed to extend for a distance and thus become the weather for an area. But this still results in discontinuities along a path going from one area to another. Interpolation, whether linear or curvilinear, between the defined locations often gives the best approximation to the weather along a path. As before, the weather description changes with variations in the framework, in this case the spatial framework.

When using separate weather models at multiple locations, there may be a need to correlate the weather at one location with the weather at another location. This "spatial correlation" becomes very important if detailed knowledge of the weather along paths is required. Interpolation will assure a value for the weather between any two points, but the same value may not result for an intersecting path between two other points unless there is some correlation in the generation of the weather. This complicates the weather generation since it becomes a function of not only the past weather condition at the location, but also of the past and expected future weather at all adjacent locations. Methods of modeling spatial correlation are currently under investigation.

A Mathematical Formulation for Weather

Often it becomes necessary to derive a mathematical formulation of the weather before a weather effects model can be constructed. Both a weather model that synthesizes the weather and a weather forecasting mechanism need a mathematical basis. The formulation must be such that if both the synthesis model and the forecasting mechanism are used, they are consistent. A weather model may not require a synthesis model of the weather if actual data is available.

A formulation of weather conditions as a Markov chain process has proved most amenable to the construction of both a synthesis model and a forecasting mechanism while giving results of sufficient accuracy. Most of the available literature concerning the use of Markov chains in weather modeling deals with precipitation modeling, [1, 2, 3, 4] but the method is general and can be applied to many weather phenomena.

A Markov chain process is a process where the outcome can be expressed in probabilities such that the outcome of a given step of the process depends only upon the outcome of the immediately preceding step with this dependence being the same at all steps. The process is a series of conditions (steps) each separated by a fixed time interval. The process is described by giving the initial probability distribution of being in any state at time zero, and by giving the fixed conditional probabilities of a particular outcome given a particular preceding outcome.

A Markov chain process formulation of weather consists of a specification of the initial state of the weather and a transition probability matrix. The matrix gives the probability of a weather state existing one time interval from the present, given the current weather state. This time interval separates the steps of the Markov process and is the time interval associated with a given transition matrix. Since it is a matrix of probabilities, each row sums to 1.0. The use of the matrix is independent of the time at which it is used. Figure 1 shows a simple two-state transition matrix and the resultant Markov chain.

TRANSITION MATRIX

FROM T_i \ TO T_{i+1}	STATE A	STATE B
STATE A	0.70	0.30
STATE B	0.10	0.90

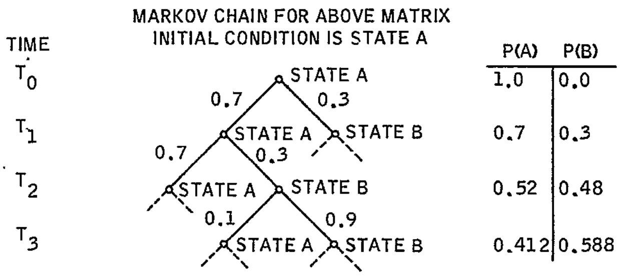


Figure 1. A Simple Markov Chain Weather Model

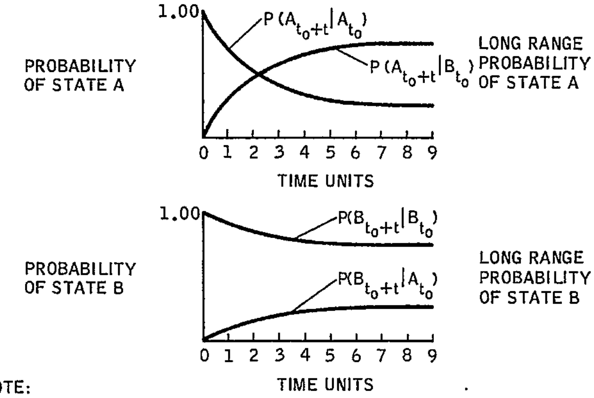
The forecasting technique associated with a Markov chain weather model is the use of persistence curves. These curves depict for a given location the probability of a particular weather state existing any number of time units from the present time, given the present state. This does not necessarily mean that the state remained unchanged throughout the period, since it may have recurred after a change to another state. This is due to the discreteness in the observations that form the persistence curves. In the weather model, the curves are derived from the transition matrix. Figure 2 shows the persistence curves associated with the transition matrix of Figure 1. The persistence curves give the best prediction possible for future conditions when the weather is formulated as a Markov chain process.

Weather Modeling

A weather effects model has three distinct sections:

1. The model of weather conditions.
2. The predictive mechanism.
3. The effects model.

The effects model is the combination of relationships, expressions, and logic that modifies the operation of the primary model based upon the value of the weather. A predictive mechanism is available to "forecast" future weather conditions. The weather model is constructed



NOTE:

THESE APPLY ONLY AT THE LOCATION WHERE THE ASSOCIATED TRANSITION MATRIX IS USED TO GENERATE THE WEATHER.

Figure 2. Persistence Curves for Matrix Given in Figure 1.

to provide the weather as a function of both location and time.

Weather modeling may be approached in one of two ways. One way is to use actual data directly in the weather model. The second way is to construct a model that uses probability relationships and random numbers to create the weather; that is, a model that synthesizes the weather. The formulation of these two approaches, and the advantages and disadvantages of each approach will be discussed.

The objective of the weather model is to provide the foreground model with information on the weather at the times and locations required. If the times and/or locations may take on any value within some defined continuum, the weather model must be capable of providing results continuously in time and in space. However, if the times and locations required are fully specified prior to running of the simulations, then the weather model becomes simpler. In this paper the former situation is assumed to exist.

In a weather model that directly uses meteorological observations, the model's task is the entry of the observations into the simulation. The observations will generally be stored on disk files or on magnetic tape due to the large quantity of data involved. The data must be time sequenced when stored. Thus, the observations at a particular time for all locations are stored before the set of observations for the following time at any location. This assures entry of the observations into the primary model in the order best suited to the primary model's operation with the fewest possible input/output operations.

The major advantage in using a time-sequenced, actual observation model is the control over the predictive mechanism's accuracy. The mechanism can be a look-ahead procedure, that is, it predicts future weather by looking at the observations before they are required by the weather model. This provides control over the degree of predictive accuracy. It allows 100% accuracy if necessary. However, computer memory is required for storage of the data for the longest interval over which a prediction may be required unless elaborate tape disk handling routines are available in the simulation language. If the longest interval is only a few observation periods, the memory required should present no problem.

The ability to obtain a replica of "real-world" weather is another advantage. This approach needs to be utilized when the weather is too complex to allow a mathematical formulation that is amenable to the construction of a model and provides satisfactory replication.

There are two drawbacks to an actual observation form of model. First, there is the problem of obtaining the data to be used. The data must span enough time to ensure including the weather extremes. Data may not need to be obtained for the entire simulated time span, for it is possible to recycle through the data if this does not cause cyclical spurious results. Secondly, the model's running time may be increased significantly by the added input/output operations required to access the data. If the model's time span is many orders of magnitude greater than the weather observation interval, then the approach may be impractical. For example, with hourly observations and a simulation length of ten years, there are 87,600 accesses of the observations to perform. The time used by input/output operations will obviously depend upon the simulation language and the hardware being used, but this time should be taken into account when considering use of this approach.

Using a routine that synthesizes the weather is the second approach to building a weather model. The synthesizing approach described here uses the Markov chain and persistence curve formulation described earlier. At each occurrence of some fixed time interval, the state of the weather is used to generate the state in the next interval. This process uses as input information the relationships desired in the resultant weather, for example, the ratio of cloudy to sunny days. This approach has been used at Convair division with a high degree of success. It is flexible, quick running, and requires little computer memory.

The heart of the weather generation routine is the transition matrix. This matrix is formed from the probabilities of a weather condition occurring at time t_{i+1} given the weather condition at time t_i. It is constructed for a fixed time interval. Therefore, the matrix and the expressed relationships depend on the preceding weather condition only and apply at any time t_i. Thus, it is a Markov chain process that is being generated.

The routine's operation is very simple. The routine is initialized by specifying the initial weather condition. It then generates new weather at each lapsing of the fixed time interval (the step in the Markov process) used in forming the transition matrix. A random number uniformly distributed between 0 and 1.0 is used to determine the weather condition for the next period, and so on. Figure 3 is a flow diagram of this routine.

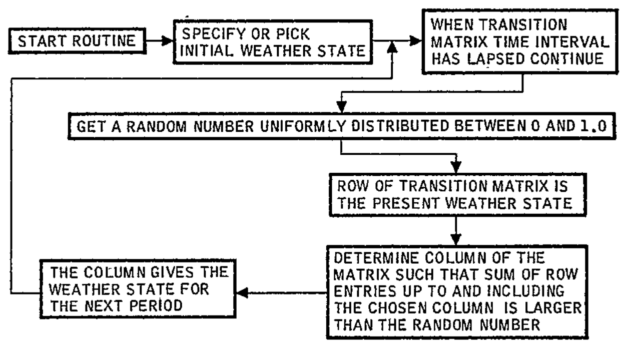


Figure 3. Flow Diagram of Markov Chain Process Weather Model

The major advantage to using a Markov generator for the weather is the ease of altering the weather generated for multiple tests of a model. Changing the sequence of random numbers used in forming the weather provides the means for altering the weather — and in most simulation languages these can be readily changed by using a new random number seed when the model starts. The entries in the transition matrix are also easily modified. Thus, the effects of different relationships between weather states can be determined.

Another advantage is the ease with which periodic weather "observations" are obtained when only the general relationships among various conditions are known. This is very useful when insufficient actual data exists, since the weather model can use hypothesized weather relationships. This weather model formulation also allows sensitivity analyses to be performed that can help determine the weather data/system effectiveness relationships and the type of weather data needed for further studies.

A drawback to this approach is the lack of control over the predictive mechanism's errors. The persistence curve is merely a maximum likelihood value for the probability of observing a particular condition. Therefore, in this weather model there is no way of forcing a desired degree of forecast accuracy.

In both forms of weather modeling there is a need for consistency between the weather generation section and the predictive mechanism. In the actual observation model with a look-ahead predictive technique there is perfect consistency. With the Markov model and persistence curve predictor there is only one persistence curve that is consistent with any given transition matrix. By not having consistency between them, additional forecast errors are introduced.

Implementing a Weather Background in GPSS/360

Implementation of a weather background can now be examined. This will be examined from the viewpoint of utilizing a simulation model constructed with International Business Machines Corporation's General Purpose Simulation System/360 (GPSS/360). The techniques required by a foreground-background interaction and the use of tapes in a background section are discussed. A complete Markov chain weather model is presented. These demonstrate the feasibility and desirability of using GPSS/360 to simulate a weather environment.

The interaction between the background and foreground sections of a GPSS simulation model is a transfer of information from one section to the other. This communication may be one-way, that is, background supplying the foreground section or two-way, that is, each supplying the other. This requirement for communication necessitates establishing control procedures to assure accurate and complete data transferral. If the data can be used at the same clock time as it can be changed, there might arise the use of both pre- and post-change data and, thus, inconsistent data. The control procedures must prevent this.

There are two basic forms of communication:

1. Communication via transactions.
2. Communication via data storage.

Each of these forms and its associated control techniques will be discussed.

One form of communication uses a transaction flow from one section of the model to another. When a transaction is used to effect the communication of data, it is generally the parameters of the transaction that hold the data. The transaction must pass through the parts of the model that need the information. If the transaction is diverted directly from the background section into the primary section, it may prove hard to control. A better approach is to store the transaction on a user chain until its data is required. At that time, unlink the transaction, remove and store the required data, and link the transaction back onto the chain until it is needed again or until an up-date transaction removes it. Figure 4 shows this procedure in GPSS coding. Utilizing user chains removes the transactions from active status until they are required and, thus, provides more efficient GPSS operation.

Communication via storage areas is the second basic form of communication link. The background section generates or processes data retaining it in a storage area, either a matrix or a set of savevalues. The primary section uses the values in the matrix (savevalues) whenever necessary, at which time it assumes that the values are the current or last reported information. The time at which the data was last stored is also retained in the matrix (savevalues).

The form of communication used in a simulation with a background weather environment depends primarily upon the type of weather model used. In an actual observation weather model, the data arrives in transactions. Placing it into a storage area is an unnecessary, time-consuming activity if only a small percentage of the data will actually be used. Thus, the transactions are placed on user chains. With a synthesized weather model, the generated "observations" are easily stored in a matrix.

Control is required to assure that data used by the primary section is consistent, that is, it is not composed of both prior and later data from the background model. The GPSS language allows events to occur at the same time, and therefore, the models constructed must be able to handle simultaneous events. This means that foreground model access to the data must be prevented while the data is being updated by the background model.

One control method is to use priorities. Assigning the update transactions a higher priority than the foreground model transactions often produces the desired control. However, if there are delays, the foreground model may begin operating before the data is completely updated. Such delays can be caused by SPLIT, GATE, TEST, and other blocks. Using BUFFER blocks can rectify this problem as shown in Figure 4.

Another control method is to use LOGIC SWITCHes and GATE. These are more time-consuming in terms of model execution time but give much better control capabilities. The method is shown in Figure 5 where a matrix is the communication link and access is contolled by SWITCH and GATE blocks. This technique assures that both communication sections of the model cannot be active at the same time. One section must complete its processing before the other section can commence action.

```
*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X
   ***** PRIMARY MODEL *****
                .
                .
                .
*      WEATHER VALUE DETERMINATION (PART OF WEATHER EFFECTS SECTION)
                .
                .
       UNLINK      X$WTHR,TIM14,1     REMOVE WEATHER DATA TRANSACTION FROM CHAIN
                .
                .
       LOGICR      13                 RESET SWITCH
       GATE LS     13                 GATE ON SWITCH
       SAVEVALUE   234,V97            STORE COMPUTED WEATHER VALUE
                .
                .
       TRANSFER    ,BACK3             BACK TO USE THE COMPUTED VALUE
*
 TIM14 ASSIGN      51,X232            PUT LOCATION NUMBER INTO P51
       SAVEVALUE   230,P*51           STORE WEATHER VALUE INTO X230
       LOGICS      13                 SET SWITCH
       LINK        X$WTHR,FIFO        PUT DATA TRANSACTION BACK ON CHAIN

   ***** BACKGROUND MODEL *****
                .
                .
                .
*      WEATHER STORAGE
 ENTRY SAVEVALUE   201+,K1            ENTER A WEATHER DATA UPDATE TRANSACTION
                .
                .
       UNLINK      X$WTHR,TERM7,ALL   REMOVE OLD DATA FROM CHAIN WTHR
       PRIORITY    125,BUFFER         ASSIGN DATA HIGHEST PRIORITY
       LINK        X$WTHR,FIFO        STORE DATA TRANSACTION ON CHAIN WTHR
*
 TERM7 TERMINATE   0
*
*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X
```

Figure 4. The Use of User Chains in Communication of Weather Information.

Building a model that uses time sequenced data can be done in GPSS/360. The observations that form the input are formed into a JOBTAPE. This can be done using Fortran. The observations enter the GPSS weather model as parameters of a transaction, one transaction per observation period. The transactions are stored on user chains. The primary model is then able to determine the weather condition by looking on a particular chain.

An inflexibility from one running of the model to another arises when a JOBTAPE is used. The JOBTAPE entries arrive at intervals specified by the tape itself. The starting time of the weather is given by the offset time in the JOBTAPE instruction. The primary model needs weather data to function and, thus, must begin operation after the weather model. This means that the offset time cannot be used to alter the observations that are current for the weather model at the time when the primary model begins. Another problem is the recycling of a JOBTAPE when required, since the REWIND command is not a block but a GPSS control card. One solution to these problems in using a JOBTAPE is the establishment of an executive control section. The executive section controls starting of the other sections in the model, termination of the model, statistical printouts, and JOBTAPE starts and rewinds. The executive allows a random set of records on the JOBTAPE to be used before starting the foreground model. It also recognizes the end of the JOBTAPE and causes a rewind and restart if necessary. For one such structuring of an executive control section, see Figure 6.

A complete Markov chain weather model for a two-state weather process is given in Figure 7. Study of this model will reveal how easy it is to construct such a model. The short length of the model also attests to its extremely short execution time and minimal requirements for computer memory. This is an example of a simplified Markovian weather model, since the majority of simulations would have weather processes of more than two states.

This has demonstrated the feasibility and desirability of using the General Purpose Simulation System to simulate a weather environment.

```
*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X
   ***** PRIMARY MODEL *****
              .
              .
              .
          CONFIGURATION 1
              .
              .
        GATE LR       2                    GATE ON SWITCH
        LOGICS        2                    SET SWITCH
              .
              .
*       PLACE WHERE WEATHER DATA IS USED
              .
              .
        LOGICR        2                    RESET SWITCH
              .
              .
              .
        GATE LR       2                    GATE ON SWITCH
        LOGICS        2                    SET SWITCH
              .
              .
*       ANOTHER PLACE WHERE WEATHER DATA IS USED
              .
              .
        LOGICR        2                    RESET SWITCH
              .
              .
              .

          CONFIGURATION 2 ... USED IF NEED CONSISTENT DATA WITH NO TIME CHANGE
                                INBETWEEN.
              .
              .
        GATE LR       2                    GATE ON SWITCH
        LOGICS        2                    SET SWITCH
              .
              .
*       PLACE WHERE WEATHER DATA IS USED
              .
              .
*       ANOTHER PLACE WHERE WEATHER DATA IS USED
              .
              .
        LOGICR        2                    RESET SWITCH
              .
              .
              .

   ***** BACKGROUND MODEL *****
              .
              .
              .
        WEATHER GENERATOR
              .
              .
        GATE LR       2                    GATE ON SWITCH
        LOGICS        2                    SET SWITCH
              .
              .
*       PERFORM UPDATES ON WEATHER DATA MATRIX
              .
              .
        LOGICR        2                    RESET SWITCH
        ADVANCE       V18                  TIME IS ADVANCED
              .
              .
        TRANSFER      .BACK                GO BACK TO EARLIER PART OF SECTION
*
*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X
```

Figure 5. Logic Switch and Gate Control of Communication Through a Matrix.

```
*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X
    ***** PRIMARY MODEL *****
              .
              .
              .
        GENERATE    X51,FN10,X243,,50,14,H   NOTE USE OF X243
              .
              .
        GENERATE    ,,X243                   NOTE USE OF X243
              .
              .
              .

    ***** BACKGROUND MODEL *****
              .
              .
              .
*       WEATHER MODEL
 BACK2  SAVEVALUE   14,K0                   INITIALIZE COUNTER
 BACK1        ...
              .
              .
        SAVEVALUE   14+,K1                  COUNTER FOR CONTROL ON REWIND
        TEST GE     X14,K365,BACK1          AT END OF DATA TAPE CONTINUE ON
        SPLIT       1,BACK2                 SPLIT TO HAVE TRANSACTION FOR NEXT CYCLE
        TERMINATE   1                       FORCES EXECUTIVE SECTION TO ACT. THIS IS
*                                             THE ONLY TERMINATE BLOCK WITH A NON-ZERO
*                                             TERMINATION COUNT IN THE ENTIRE MODEL.

*       EXECUTIVE CONTROL SECTION
                                            THIS EXECUTIVE ALLOWS UP TO A FOUR YEAR
                                             SIMULATION WITH A WEATHER TAPE OF DAILY
                                             DATA FOR A YEAR.
              .
              .
              .
*       MODEL TIMING                        * THE MODEL IS TO RUN FOR A FIXED      *
     10 VARIABLE    K1-K2                   *  TIME. THUS A TIMING SECTION IS      *
        GENERATE    ,,X243                  *  USED TO END OPERATION OF THE MODEL. *
        ADVANCE     X$TIME                  *  THE ADVANCE V10 WILL CAUSE A GPSS   *
        ADVANCE     V10                     *  ERROR AND HALT THE SIMULATION.      *
              .
              .
        INITIAL     X243,110                THIS IS THE OFFSET TIME FOR START OF
*                                            PRIMARY MODEL RELATIVE TO THE WEATHER.
        CLEAR       X243                    CLEAR MODEL EXCEPT FOR X243
        START       1,NP,,1                 START MODEL
        REWIND      JOBTA1                  REWIND JOBTAPE 1
        START       1,,,1                   START MODEL
        REWIND      JOBTA1                  REWIND JOBTAPE 1
        START       1,NP,,1                 START MODEL
        REWIND      JOBTA1                  REWIND JOBTAPE 1
        START       1,,,1                   START MODEL
*
*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X
```

Figure 6. JOBTAPE Control Via an Executive Control Section.

```
*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X
    ***** BACKGROUND MODEL *****
              .
              .
              .
*   WEATHER GENERATION SUBMODEL
        GENERATE    ,,,1,100                ONE TRANSACTION WITH PRIORITY OF 100
        MSAVEVALUE  2,1,1,700               INITIALIZE TRANSITION MATRIX
        MSAVEVALUE  2,2,1,100               INITIALIZE TRANSITION MATRIX
        ASSIGN      1,RN1                   * THESE TWO BLOCKS RANDOMLY SELECT *
        TRANSFER    ,*1,STATA,STATB         *    INITIAL WEATHER STATE         *
*
 STATA  SAVEVALUE   15,K1                   STORE STATE -- 1 = STATE A
        ADVANCE     10                      ADVANCE TRANSITION MATRIX TIME INTERVAL
        TEST G      RN2,MX2(1,1),STATA+1       DOES THE WEATHER STATE CHANGE...
*                                           CHANGE TO STATE B
 STATB  SAVEVALUE   15,K2                   STORE STATE -- 2 = STATE B
        ADVANCE     10                      ADVANCE TRANSITION MATRIX TIME INTERVAL
        TEST G      RN2,MX2(2,1),STATB+1       DOES THE WEATHER STATE CHANGE...
        TRANSFER    ,STATA                  CHANGE TO STATE A
*
*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X*X
```

Figure 7. Two-state Markov Chain Process Weather Model.

FOOTNOTES/BIBLIOGRAPHY

1. Caskey, J. E. Jr., "A Markov Chain Model for the Probability of Precipitation Occurrence in Intervals of Various Lengths," Monthly Weather Review, Vol. 91, No. 6. 1963, pp. 298-301.

2. Feyerherm, A. M., and L. D. Bark, "Goodness of Fit of a Markov Chain Model for Sequences of Wet and Dry Days," Journal of Applied Meteorology, Vol. 6, 1967, pp. 770-773.

3. Feyerherm, A. M., and L. D. Bark, "Statistical Methods for Persistent Precipitation Patterns," Journal of Applied Meteorology, Vol. 4, 1965, pp. 320-328.

4. Weiss, L. L., "Sequences of Wet or Dry Days Described by a Markov Chain Probability Model," Monthly Weather Review, Vol. 92, No. 4, 1964, pp. 169-176.