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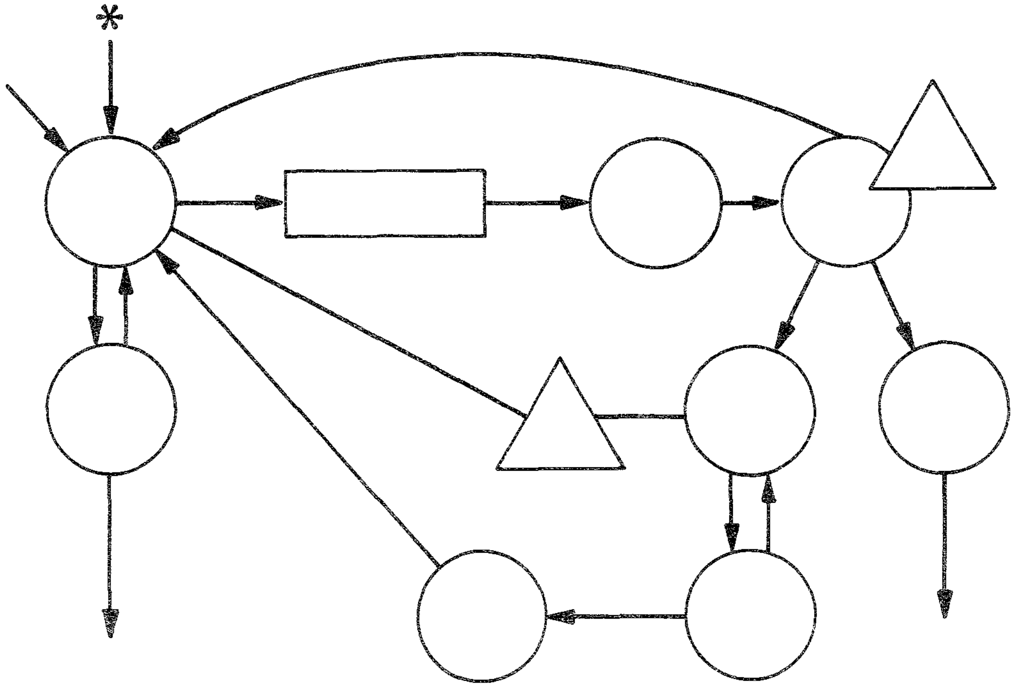

SAAM

27

SAAM MANUAL

(Simulation, Analysis and Modeling)

by

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FOREWORD

SAAM is a digital computer program developed for the analysis of data in terms of models. It permits simulation and data fitting, and contains various techniques encountered in model building.

Although developed primarily for biological systems and more specifically for kinetic models, the program is of general utility. It differs from other simulation and data fitting programs in that its "language" is geared to the bio-medical "system" investigator, and its elements and computational procedures are counterparts of conceptualizations and experimental methodologies employed by the investigator.

Model building is complicated and requires--in addition to intuition and speculation--knowledge of mathematical and statistical procedures and their limitations. This manual is only a limited description of the procedures used in SAAM and some of their limitations. For additional background material the reader is referred to the reference section.

SAAM is a large, complex program and is perennially being extended and revised. (It is written in FORTRAN IV and contains more than 35,000 statements.) Like any large program, it is difficult to debug fully, and undoubtedly contains some undetected errors, even though parts of it date back to 1959. It is recommended, therefore, that users run known test problems of their own. We also invite users to call to our attention any questionable results which may be attributed to the program and not to errors in the data.

This manual is for the SAAM27 version of the program. Revisions and updates appear occasionally, and will be sent to those who request that their names be placed on our mailing list. Each page of the manual contains the date when substantive changes were made. The front page contains the date of release of the manual. The printed output from SAAM also carries a date indicating when revisions were last made in the program.

S E C T I O N I

INTRODUCTION

INTRODUCTION

SAAM is designed as a tool for the study and testing of mathematical models. Any set of mathematical equations (differential, integral or algebraic) or functions may serve as a model provided an analytical or numerical procedure exists for its solution. A library of model types (Section VI) is incorporated within the program for routine use. The library is open ended and new model types may be added.

The program uses a common data input format for all model types. This is made possible through the use of a single set of computational parameters and variables in the program. The equivalence between the parameters of a particular model type and those within SAAM is given in the section on Model Types.

Models may be solved in a BATCH or CONVERSATIONAL mode. The BATCH program is referred to as SAAM BATCH and the conversational - as CONSAM. This manual applies to both, although additional display and graphic commands are available in CONSAM. A separate manual is available for the latter.

S E C T I O N II

GENERAL FEATURES

COMPUTATIONAL STRUCTURE

We describe the solution or response of a model by functions F(I,T), where I is an index number and T is a vector of independent variables (e.g., time). F depends on the nature of the model, its parameters and constraints (e.g., initial conditions).

Experimental data, QO(J,T), are observables of the system and as such are ESTIMATES of some theoretical values QC(J,T) which are functions of the F(I,T), T, and the parameters. J is an assigned component number for a particular set of observations (real or simulated).

In general, we define:

QC(J,T) = K(J)*H(F,T,PAR)

where PAR are parameters and H is a general description of the functional relation. K(J) is a proportionality constant associated with component J.

H may take a number of forms, for example:

F(J,T)	
ΣS(J,I)*F(I,T)	(called SUMMER) S(J,I) are special SAAM parameters
G(N)	(a defined function, with index N).

These are specified for each datum directly, by code or by default.

The calculation of a specified set of QC(J,T), given a model, parameter values and T, is referred to as SIMULATION.

The fitting of a model to data implies the derivation of a set of parameter values for which the calculated QC(J,T) "best" fit the data, QO(J,T). This involves three stages of computations:

1. Solution of F(I,T)

This phase calculates F(I,T), given a model, parameter values and T. The computations depend on the TYPE of model and on the available COMPUTATIONAL methods. For example, differential equations are solved numerically using a 4th order Runge-Kutta method (model type 1). Linear differential equations with constant coefficients are also solved using analytic (model type 2) and other methods (model type 10). Each method of solution is coded as a separate subroutine in SAAM. During the execution of a particular problem the appropriate subroutines required for the problem are used either by default or as specified in the problem deck.

2. Calculation of QC(J,T)

The function H as designated for each datum is calculated, multiplied by K(J) and the result stored as QC(J,T). If the component number is zero, no multiplication by K(o) takes place.

3. Adjustment of Parameters.

This stage involves the adjustment of the parameter values of the model until the calculated QC(J,T) "best" fit the observations QO(J,T).

From the point of view of adjustment of parameters to fit data, the parameters are classified as: FIXED, DEPENDENT, or ADJUSTABLE.

FIXED parameters have values assigned in the problem deck. They may be changed during a solution but always in a predetermined manner, independently of the fit. Such changes may occur, for example, in connection with solution interrupts (T-Interrupts).

DEPENDENT parameters (parameter-dependence) have values determined by prescribed equations involving other parameters and/or constants and can only adjust indirectly during the fitting of data. A parameter, once classified as dependent, remains so throughout the solution and always obeys the same dependence relation.

ADJUSTABLE parameters are free to adjust as required by the data. Each adjustable parameter is entered with an initial estimate and a minimum and maximum limit. (Initial estimates for the linear parameters S(I,J) and K(J) may be omitted except when their initial estimates are required for the calculation of other functions). The assigned upper and lower limits are not violated during data fitting. The program recognizes a parameter as adjustable when its upper limit is greater than its lower one.

Two classes of adjustable parameters are identified in SAAM - one LINEAR with respect to QC(J,T) and one NON-LINEAR. The K(J) and S(J,I) comprise the linear class (sometimes also referred to as SECONDARY PARAMETERS) while the L(I,J), P(J), and others comprise the non-linear class (sometimes also referred to as PRIMARY PARAMETERS). When the linear parameter values are not known, their values may be estimated from the observed quantities QO(J,T) by the use of linear regression, for example,

$$QO(J,T) = K(J)*\Sigma S(J,I)*F(I,T) \qquad \text{(For all J and T)}$$

provided the number of independent observations is equal to or greater than the number of unknowns.

When the parameters are non-linear with respect to the QC(J,T), a non-linear least squares fitting procedure is employed. Starting with initial estimates for the parameter values, one calculates the QC(J,T). These are compared to the observed values QO(J,T) and the parameter values are adjusted to minimize the difference between the calculated and observed values, using a least squares method.

Some parameters (fixed, dependent or adjustable) may also be FUNCTION-DEPENDENT (fn-dependent). This means that during the solution their values are continuously modified by functions in a specified way. Since the functions can depend on T and F(I,T), this permits the solution of time dependent and/or non-linear differential equations. This feature may not be used with all model types.

NOTE: In equations involving parameters, the function-dependent part of the parameters is excluded.

A standard deviation can be assigned to the value of an adjustable parameter as an item of independent statistical information. The parameter value and its standard deviation are combined statistically with the rest of the data to derive estimates for the adjustable parameters. More extensive statistical constraints can also be entered. It should be noted that statistical constraints on parameters are independent of the upper and lower limits. The limits are NOT involved in CALCULATING corrections for the adjustable parameters but are used only to LIMIT the magnitude of the corrections.

PROBLEM DECK

A problem deck consists of information describing the user's model, solution method, data, desired computations and outputs.

The first card of a deck serves to identify the start of a problem ('A' in column 1) and the version of the program to be used (e.g., 'SAAM27'). The next three cards (in FIXED order) specify method of solution, control constants and output options.

All other information is entered under defined HEADINGS. Entries under headings have fixed format or are written as equations (FORTRAN-like in form) which describe functions or parameter relationships.

Comment cards ('C' in column one) may be inserted anywhere in the deck by the user. They are listed by SAAM as part of the problem deck but are ignored operationally. A 'Y' entry in column 1 may be used as an instruction to ignore all the cards that follow until a new problem is encountered.

Control cards may also be used under some headings to modify subsequent entries or to generate a new string of entries.

The solution of a problem may be segmented into blocks called T-interrupts. Each block (except for the first one) is identified by an index I as TC(I). Parameter and F(J,T) values may be redefined at the beginning of each T-interrupt block.

A run deck consists of one or more problem decks stacked one behind the other.

A run deck is terminated with a card having a 'Z' entry in col. 1. This card is optional on some machines.

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SAAM DICTIONARY

Certain names are recognized by SAAM as having special meaning. Some of these serve as instructions and some as variables in equations. The interpretation of names depends on the model type chosen from the SAAM library.

The following names may be used both as instructions and as variables in equations:

L(I,J)	-L Parameters (when used as an instruction Fn-dependence is included in the calculated value in L(I,J))
UF(I)	-UF parameters "
DT(I)	-Delay parameters "
S(I,J)	-S parameters
K(I)	-K parameters
P(I)	-P parameters
DN(I)	-Resolution parameters
G(I)	-G parameters
T	-Independent variable (usually time)
TH	-Second independent variable
U(I)	-Steady state input (differential equations)
M(I)	-Steady state solutions (differential equations)
G(I)	-Special function (G-function) defined by an equation somewhere in the problem deck: G(I) = . . .
F(I,T)	-Model solution value for component I at T.
IC(I)	-Initial conditions (differential equations)
UF(I)	-UF-function defined by an equation: UF(I) = . . .
FF(I)	-Special function (FF-function) defined under the H DATa heading: FF(I) = . . .
DF(I)	-Special function (DF-function) defined under the H DATa heading: DF(I) = . . .
R(I,J)	-Value of (L(I,J)*Z)®M(J) where ®Z is a 'fn-dependence operator'.

The following names may be used as instructions only:

SA	-Calculate ratio F(I,T)/M(I) (specific activity)
QO(I)	-Set F(J,T) to QO(I,T)/K(I), (J is the component number appearing with the instruction)*.
QF(I)	-Set F(J,T) to value of FF(I,T), (J is the component number appearing with the instruction)**.
INF	-Set value of T to very large number (10^{38})
N	-NULL operator

* In versions of SAAM prior to Apr. 1,1978, division by K(J) was used instead of K(I).

**In versions of SAAM prior to Apr. 1,1978, FF(I,T)/K(J) was used instead of FF(I,T).

INPUT FORMATS

Information is entered either in FIXED fields or as EQUATIONS.

Fixed fields

Fixed fields are defined as INTEGER, DECIMAL or HOLLERITH.

Integer fields require that the data be NUMERIC. No decimal points are allowed and the entry must be right justified.

Decimal fields require NUMERIC entries which can be placed anywhere within the designated field. The FORTRAN E format is also allowed.

Hollerith fields permit any character entry.

SAAM uses several formats which require fixed fields. These are discussed later and shown in the appendix.

Equations

An equation is any relation containing an '=' sign. It may be in explicit form, such as

```
G(1) = .5*L(3,2)/EXP(-L(2,3)*T)
L(2,3) = L(3,2) + L(4,9)/M(6)
```

or in implicit form, e.g.

```
L(2,3) + L(2,4) = L(1,2) + G(5)
```

Equations may use the arithmetic operations +, -, *, /, ** and the symbols SIN, COS, LOG(base e), ALOG(base e), AMAX1, AMIN1, EXP, TAN, ATAN, SQRT, ALOG10. Variable names in equations are restricted to those listed in the SAAM dictionary.

FORTRAN hierarchy of arithmetic operations is followed in interpreting the equations. One or more cards may be used to enter an equation.

First equation card

Col 1	Blank - When the equation is to be considered as an instruction to be executed at its point of entry in the problem deck. 'X' - when an explicit definition of a function is given with the sole intent of storing it so that it can be referred to and used elsewhere in the problem.
Col 2 - 55	Equation terms. This field must include the '=' sign and must end with an arithmetic operation symbol if the equation is carried over to another card.
Col 56 - 60	For explicit equations defining parameters - same entries as for PARAMETERS (fixed field entries).

Continuation cards (up to 5)

Col 2 - 72	Equation terms continued. The last character on each card must be an arithmetic operation symbol (+,-,/,*,**), if the equation is carried over to a subsequent card.

G, UF AND FF FUNCTIONS

The function denoted by G(I), FF(I), or UF(I) where I is an integer, has special significance when defined explicitly. Once defined somewhere in the input stream it can be used in various field entries or relations. The definition follows the equation format. (These functions cannot be defined under the headings MAT, ICC, PCC and SCC.)

HEADINGS

A heading card is used to identify the type of entries that follow it. It contains the following identifiers:

Column 1	the letter 'H'
Column 3 - 5	a THREE character name

A heading card may further identify a block of entries as a segment of a larger block, or as a particular SOLUTION BLOCK (T-interrupt). Each solution block (except the first) is defined and indexed as a TC(K) block.

Column 13 - 25	(I) - segment index number I = 1, ..., 99.
Column 27 - 42	TC(K) - for T-interrupt block K K = 1, ..., 20.

A heading card also implies a format for the entries that follow it. The following heading names and corresponding formats are presently used.

H	DATa	Data format
H	PAR	Parameter format
H	LAM	" "
H	SIG	" "
H	KAP	" "
H	INItial conditions	" "
H	STEady State	" "
H	DEPendence Relations	Equation format
H	STAtistical Information	Equation format
H	MATrix	Matrix format
H	ICC	Parameter format
H	PCC	Special format
H	SCC	Parameter format
H	SS3	Special format
H	FORmat	Defines a format
H	ADD	Governed by the preceding heading in input stream.
H	SPEcial	Hollerith format

DATA, PARAMETER and MATRIX formats are shown in APPENDIX A. SPECIAL formats are defined under their corresponding headings.

All headings having identical names, TC indices and segment numbers, are combined in the program under a single heading in the order in which they appear in the input.

LIMITS IMPOSED BY PROGRAM

Because of limitations in the computer the following limits are imposed by the SAAM program:

Number of components	< 26
Number of parameters	< 75
Number of adjustable parameters	< 26
Number of data and "statistical constraints" plus number of T-interrupts	<251
Number of T-interrupts	< 21
Number of cards in a problem deck	<551
Number of parentheses in equation (including those added internally by SAAM)	< 31

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PARAMETERS

	Fixed	Dep.	Fn-Dep.	Spec. Modi.[1]	ADJUSTABLE Dir.	ADJUSTABLE Indir.	STATISTICS Lin.	STATISTICS Non-Lin.	SUBSCRIPTS Comp. Rel.[2]	SUBSCRIPTS Range
L(I,J)	x	x	x	x	x			x	x	$0 \leq I < 26$ $0 < J < 26$
S(I,J)	x	x			x		x		x	$0 < I < 26$ $0 < J < 26$
K(I)	x	x			x		x		x	$0 < I < 26$
K(N)	x	x			x		x			$26 < N < 100$
UF(I)[3]	x	x	x		x			x	x	$0 < I < 26$
DT(I)	x	x	x		x			x	x	$0 < I < 26$
DN(I)	x	x							x	$0 < I < 26$
IC(I)	x	x				x			x	$0 < I < 26$
M(I)	x	x				x			x	$0 < I < 26$
U(I)	x	x				x			x	$0 < I < 26$
P(I)	x	x			x			x		$0 < I < 100$
G(I)[3]	x	x			x			x		$0 < I < 100$

[1] Further modification of parameter possible by entry in FIELD 6 (Column 60).

[2] This represents association of a subscript with a component or compartment.

[3] May also be defined as functions under H DATa or H PAR.

S E C T I O N III

INPUT

PROBLEM DECK

CARD 1

Card 1 must be used as the start of a problem deck. A number of problem decks may be stacked one behind the other in a single run.

Col 1	Enter 'A' to designate the start of a problem. Enter 'M' for problem to be recorded and referenced for subsequent retrievals - but not to be solved.
Col 3 - 8	The version of the program (e.g., SAAM27) must be entered.
Col 10 - 20	Problem identification, three initials followed by up to eight characters (letters, numbers, decimal pts.). The problem identification entry is only needed when all or part of this problem deck is called for in subsequent or preceding problems.
Col 31 - 72	Any entries are permitted in this field (e.g. user's name, problem description, etc.).

CARD 2*(optional)

Col 1	Enter '2' (This entry is optional.)
Col 4 - 5	Index of largest component number appearing in the model. Default value=25 which is subsequently reduced to the highest component number encountered in the problem.
Col 9 - 10	Maximum number of iterations for fitting data (Usually 6 to 10). When the entry is zero (or blank), only a single solution is obtained.
Col 17 - 19	This entry, jointly with that in Col 23-33, is required only if all the information of another problem deck is to be added to the current problem. BLANK - requested problem is in the input stream of the current run. Other entries not yet implemented.
Col 23 - 33	Identification of requested problem exactly as it appears on Card 1 of the problem requested. BLANK - No problem is requested.
Col 49 - 50	Model code for type of solution requested. When this entry is blank, SAAM assumes a compartmental model and selects from among model codes 2, 10 and 8, in that order.
Col 51 - 65	Entries for special model types (described under model types).
Col 66 - 70	Request to SAVE or READ KOMN and other data files during execution of SAAM for subsequent reentry by SAAM or by CONVERSATIONAL SAAM. Col 66--enter '5' to save KOMN and continue solution. enter '6' to read KOMN and continue solution. Col 67-70 enter '2067' to designate entry or exit flagpoint. (Flag 2 in subroutine 067.) NTAPE4, NTAPE6 and NUNIT are the SAAM names used for the above files.

*Note: Card 2 may be omitted in which case all entries are taken as blank or default values.

CARD 3*(optional)

Column 1	Enter '3'. This may be omitted if card 3 follows card 2.
Column 2 - 10	Time Factor - Blank, unless the internally allotted time for a single solution of differential equations is to be modified. Internally allotted time = 1. as a reference. Enter smaller or larger value as modification factor.
Column 21 - 30	BLANK. See Section VII-5 for additional information.
Column 31 - 40	P1 - This entry indicates the fractional change in adjustable parameters used to calculate the partial derivatives of the data with respect to parameters. Default value=.01
Column 41 - 50	E - This is a convergence constant. Default value=.98
Column 51 - 60	PREC Constant. (Not for User's use.)
Column 61 - 70	CONMIN - This is also a convergence constant. Default value=.98.

*Note: When card 3 is omitted the default values are assumed.

CARD 4* (optional)

This is a print options card. Blank or zero in any of the fields yields no output for that option.

Column 1	Enter '4'. This may be omitted if card 4 follows card 3.
Column 2	'1' - print covariance matrix. '2' - punch covariance matrix '3' - print and punch covariance matrix
Column 3	'1' - print partials matrix.
Column 4	Plot options: '1' - semi-log 2 page plot. '2' - semi-log 1 page plot. '3' - linear 2 page plot. '4' - linear 1 page plot. '5' - log/log 2 page plot '6' - log/log 1 page plot '7' - semi-log plot of all components, semi-log plot of Comp24 vs Comp25 '8' - linear plot of all components, semi-log plot of Comp24 vs Comp25 '9' - semi-log plot of all components, log/log plot of Comp24 vs Comp25

Note: Components having 3 or less data are not plotted.

Column 5	'1' - print the normal equations coefficient (A) matrix.
	'2' - punch the normal equations coefficient (A) matrix.
	'3' - print and punch the normal equations coefficient (A) matrix.
Column 6	'1' - print intermediate results.
Column 7	'1' - print reorganized problem information.
Column 8	'1' - RES VECTOR calculation printout.
Column 9	'1' - save a new deck (from calculated values) on designated file (NTAPE8 is the SAAM name for this file).
Column 10	'1' - print zeroeth iteration results (if number of iterations called for is greater than zero or covariance and partials are requested under '0' iterations).
Column 11	'1' - print data deck card images.
Column 13	'1' - use only 'critical points' in calculating normal equations.

*Note: Card 4 may be omitted in which case all entries are taken as blank except for:
'2' in column 4
'1' in column 11

DATA AND INSTRUCTIONS

H DATa

H DATa is the heading under which the solution pattern is defined and carried out. Each card under this heading is an instruction directly defined, or implied by its entries and the model code.

Fixed field entries

Column 1	Blank
Column 2 - 3	Component number assigned to the function to be calculated; Blank implies 'zero' component.
Column 4 - 11	Category - instruction or type of function to be calculated: Blank - Calculate an F(I,T) determined by model code and component number entered in column 2 - 3. Dictionary name - calculate or get value for requested variable name, except when entry is instruction, such as T, QO, . . . (see sec. II).
Column 13 - 25	Value of T. If a calculation for T equal to infinity is desired enter INF.
Column 27 - 40	Observed value
Column 42 - 55	Standard deviation of observed value
Column 56	Enter 'P' to tag a 'critical point'. A special plot of QC(I)/QC(I) is generated for all critical points.
Column 57	Category modification. Variable names - entered or implied by the category field may be modified by entries in column 57 as follows: D - Calculate left derivative of category entry. R - Calculate right derivative of category entry. A - Calculate effective left exponential decay constant for requested function. B - Calculate effective right exponential delay constant for requested function.

Note: The exponential decay constant is defined as the negative of the derivative divided by the value (QC) of the datum. The request for 'left' or 'right' will determine whether the calculation will precede or follow changes in F(I,T) resulting from QO or QF instructions at the same value of T.

Column 62 - 72	TH value

Equation Entries

An explicit equation defining a special function (G, FF, UF, DF) may be entered under the heading H DAT either with or without an X in column 1. With an X in column 1 the equation is stored for use as may be requested anywhere in the problem. With column 1 blank the equation is stored as before but, in addition, a datum is automatically generated for that function (component = 0, G(I), FF(I), UF(I), DF(I) in category field, T = to T of preceding datum, statistical weight = 0).

The entry 'G(I)' ('FF(I)', 'UF(I)', 'DF(I)') in formatted form under CATEGORY together with a defining equation for that special function permits the calculation of a desired function and its fitting to 'observed values'.

Control Cards

Control cards may be used to simplify entries in problem decks or to modify data fields. There are two types of control cards under the H DAT heading: a FIELD MODIFICATION card and a DATA GENERATION card. Entries for the control cards follow the DATA FORMAT.

<u>FIELD MODIFICATION control card</u>

This control card modifies, defines or interprets the entries on the data cards that <u>follow</u> it. Each field on this card controls the corresponding field on the data cards. When a field on the control card is blank, it exercises no control over that field. Control is terminated by another control card or by a heading card for a new T-interrupt.

Column 1	Enter '1'. This signifies FIELD MODIFICATION control card.
Column 2 - 3	Entry <u>replaces</u> component number on succeeding cards.
Column 4 - 11	Entry <u>replaces</u> category on succeeding cards. The special entry N blanks the category entry on succeeding cards.
Column 13 - 25	Entry ⊛X modifies subsequent card entries Y to yield new values, Y', defined by Y'=Y⊛X. ⊛ is an operator which may be one of the following: +, -, *, /. X may be any number or a defined function G(I).
Column 27 - 40	Same as Cols 13 - 25.
Column 42 - 55	Enter 'SD = X' where X is the desired standard deviation to be applied to the observations that follow.

Enter 'FSD = X' where X is the desired fractional standard deviation (coefficient of variance) to be applied to the observations that follow.
(When an observation value is zero, the weight for that observation is set to zero. This can be overcome by using an 'SD' option.)

Enter 'WT = X' where X is the desired statistical weight to be applied to the observations that follow. For zero weight WT=0 may be used.

Enter 'RQO=X' when a standard deviation proportional to the square root of the observation is to be assigned to the data that follow. (SD = square root X*QO) 'X' is the square of the proportionality constant.

Enter 'SD', 'FSD', 'WT' or 'RQO' to denote meaning of entries on each succeeding card. When this field is blank, SD is assumed by default.

Column 56 — Enter 'P' for critical point entry on succeeding cards. Enter 'N' to blank entries on succeeding cards.

Column 57 — Enter 'D', 'R', 'A' or 'B' for entry on succeeding cards. Enter 'N' to blank entries on succeeding cards.

Column 62 - 70 — Same as Cols 13 - 25.

NOTE: Previous SAAM conventions will be honored, in that a number without an operator in the T and TH fields will mean algebraic addition, and in the QO field - multiplication.

<u>DATA GENERATION card</u>

This control card generates data card images in increments of T starting with the T-value of the preceding entered or generated datum. All other fields of the preceding datum are carried over to the generated entries. A number of data generation cards can follow each other.

Column 1 — Enter '2' to signify DATA GENERATION card.

Column 13 - 25 — Enter value of desired T interval between generated data.

Column 42 - 55 — Enter the number of data points to be generated.

All remaining fields must be blank.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

C  EXAMPLES OF PERMISSIBLE H DAT ENTRIES

C   DECIMAL POINTS MAY BE OMITTED FOR WHOLE NUMBERS UNDER THIS HEADING.
H DAT
120                                     WT=0.
C THE ABOVE CONTROL CARD ASSIGNS COMP. NO 20 AND ZERO WEIGHT
C  TO THE FOLLOWING DATA.
   M(1)
   R(3,2)
   R(0,1)
   U(11)
101                      .0616          FSD=.2
  1         .5           6.95                                      SM2
111                      .0810          WT=0.
C                         CALCIUM 45 DATA
H DATA                   TC(1)
    T       2.3
101                                     FSD=.2
   G(5)                  4.9            1.                         DVK159
XG(4)=M(4)/(M(9)*S(7,9))
X  G(5)=.1*M(9)*S(7,9)
XG(25)=G(4)+G(9)+G(14)
   R(6,1)                15.
  3 GO      4.5          12.
C ABOVE CARD RESETS COMPARTMENT 3 CONTENTS AT T=4.5 TO ITS OBSERVED
C  VALUE.
1
  1         0.
2           .1                           10
C THE ABOVE DATA GENERATION CARD ADDS 10 DATA PTS AT INTERVALS OF
C  .1 FOR COMP NO. 1 STARTING WITH T=0.
2           1.                          15
  2
2           5.                          12.
   L(3,1)                -6.
H DAT                    TC(4)
112G(12)                                FSD=.1
X G(12)=100.-F(6,T)-F(9,T)
C  G(1) IS SERUM IODIDE CONC UG/100CC
 G(1)=.1*M(1)*S(7,1)
C  G(15) IS P.E. VOLUME OF COMP 15 (T3) IN LITERS
 G(15)=M(15)/(M(8)*S(7,8))
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

PARAMETERS

H LAM	H SIG	H KAP	H PAR
H INI	H STE	H DEP	

Fixed field entries

The above headings are used to enter K(I), L(I,J), S(I,J), P(I), IC(I), UF(I), M(I), U(I), and G(I). The PARAMETER format and the field descriptions apply to all headings.

Col 4 - 11	Enter X(I) or X(I,J). I and/or J are the indices of the parameter. (Previous formats used in SAAM 23 are still valid. Col. 4-5 index I, Col. 9-10 index J. L, S or K are implied by the headings, H LAM, H SIG and H KAP respectively).
Col 13 - 25	Value or initial estimate of parameter. It may contain the entry 'G(I)', provided G(I) is defined separately. This entry is not required for adjustable secondary parameters (S(I,J), K(I)) unless the STANDARD DEVIATION (SD) field (62 - 72) has a non-zero entry, or <u>unless it is required</u> for the initial calculations of other parameters or functions.
Col 27 - 40	Lower limit for <u>adjustable</u> parameter.
Col 42 - 55	Upper limit for <u>adjustable</u> parameter. The upper limit must always be algebraically greater than the lower limit.
Col 56	Operation code for function-dependence (Fn) specified in columns 57 - 59. The operation codes are described below.
Col 57	Blank or F - when fn-dependence refers to the function F(m,t). G - when the fn-dependence refers to a function G(m). G(m) must be explicitly defined in a separate equation.
Col 58 - 59	The integer m of F(m,t) or G(m). (No parentheses are used in this field).
Col 60	Blank - for all parameters except L(I,J). Z, K - L(I,J) modification codes. (See model codes.)
Col 62 - 72	Standard deviation for adjustable parameter. This value is associated with the initial estimate entry for a parameter.

OPERATION CODES for Fn-dependence

Let X be the value of the parameter before the operation, X' be its value after the operation and Z be the function specified in column 57 - 59, then the interpretation of fn-dependence is X' = X op Z:

Operation Code	Interpretation
+	X' = X + Z
-	X' = X - Z
*	X' = X * Z
/	X' = X / Z
5	X' = X ** Z
6	X' = EXP (X * Z)
7	X' = X for Z > 0 = X for Z = 0 = 0 for Z < 0
8	X' = X * Z for Z > 0 = 0 for Z = 0 = 0 for Z < 0
9	X' = X / Z for Z > 0 = 1.0E12 for Z = 0 = 0 for Z < 0

<u>Note</u>: Operations 7, 8, and 9 are applicable only to the L and UF parameters and are intended to provide control mechanisms.

<u>Equation entries</u>

Relations between parameters may be entered using the equations format. These DEPENDENCE equations may be written in explicit or implicit form. Linear as well as non-linear equations may be entered. SAAM tries to solve these singly or as simultaneous sets in the order in which they are entered. In solving simultaneous sets only linear equations can be handled. Non-linear equations can be solved only after the parameters that contribute to the non-linearities have been solved for through thE simultaneous linear sets. When a non-linear equation is encountered its solution is postponed until subsequent parameter solutions reduce it to linear form. If this cannot be achieved the solution terminates.

Dependence relations cannot be functions of (time) T and hence F(I,T) and T may not appear in dependence equations; but M(I), U(I), IC(I) and both G(I) and UF(I) parameters may. When M(I), U(I) and IC(I) are involved in dependence relations, they are treated like parameters and are solved simultaneously with the others provided enough information is entered. Information entered under the Headings H INI and H STE are pooled with the information under other parameter headings for a simultaneous solution.

When a relation for a parameter is given in explicit form, columns 56-59 of the first equation card may be used to give fn-dependence for that parameter.

Note: The following restrictions apply to some of the parameters:

M(I), U(I) cannot be entered in the fixed format under headings other than H STE or H SCC.

DN(I) must be constant over a time block (cannot be adjustable or fn-dependent).

IC(I) may not be independently adjustable.

P(I), K(I)*, S(I,J)* may not be fn-dependent.

* This restriction was not imposed on previous versions of SAAM and may generate a compatability problem.

```
         1         2         3         4         5         6         7         8
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

C  EXAMPLES OF PERMISSIBLE H LAM ENTRIES

C  DECIMAL POINTS MAY BE OMITTED FOR WHOLE NUMBERS UNDER THIS HEADING.
H LAM
   L(2,1)    1.6
   L(9,2)    14.3
C THE ABOVE ARE FIXED PARAMETERS
   L(1,2)=5
 L(3,2)=3.1
C TECHNICALLY L(1,2) AND L(3,2) ARE DEPENDENT PARAMETERS EVEN THOUGH
C THEIR VALUES REMAIN FIXED DURING A SOLUTION BLOCK
    L(4,3)=L(2,1) * M(4)/M(3)
  L(0,2)=L(1,2)+L(3,1)
 L(10,8)=-4.65*L(10.1)
  L(14,15)=14.    -L(16,15)
  L(0,8)=-L(10,8)-L(11,8)-L(12,8)-L(13,8)-L(9,8)-
C THE FIRST CARD OF THE EXPLICIT EQUATION DEFINING L(0,8) ENDS
C  WITH AN ARITHMETIC SYMBOL BEFORE COLUMN 56.  THE SECOND
C  CARD OF THE EQUATION MAY NOT START IN COLUMN 1.
 L(20,8)-L(16,8)-L(24,8)
C ABOVE ARE EXAMPLES OF DEPENDENCE RELATIONS.
  L(12,5)    3.           .5             4.
C L(12,5) IS AN ADJUSTABLE PARAMETER.
C K(I) AND S(I,J) MAY BE ENTERED UNDER H LAM HEADING.
 K(1)=L(6,1) * M(1)
    P(98)    14.          10              2.
    IC(1)     1.
   G(7)=5.
  L(5,4)=G(7)*L(1,2)/L(1,6)
C  G(7) CANNOT DEPEND ON T SINCE IT IS IN A DEPENDENCE EQUATION.
 L(14,8)=-L(5,8)                                       * 20
C  L(14,8) IS FN-DEPENENT ON F(20,T)
    3    2     4.         .2E-1          10                   .5
C THE ABOVE ENTRY IMPLIES AN L(3,2) SINCE IT IS UNDER THE H LAM HEADING.
   L(0,3)    G(4)
X G(2)=.169
 L(1,3)+S(5,4)=G(2)
 K(6)        .7                           5             *G2
 L(5,9)      1.                                         /F3
 L(5,6)=.8*L(6,5)                                       +G 1
X G(1)=G(2)-EXP(-L(5,9)*T)
C G(1) IS USED FOR FN-DEPENDENCE AND NOT IN A PARAMETER DEPENDENCE
C RELATION, HENCE THE USE OF T IS OK.
   S(4,7)    .2           .1              .4            7  2  .05
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

H INItial Conditions

This heading permits the entry of f(i,T(0)) values for each component i. T(0) is the initial T value for a solution. (T(0)=0 unless it is reset by a 'T' entry in the category field after the H DAT heading. See further explanation under H DAT). Only non-zero entries need be made.

Fixed field entries

Col 4 -11	Enter IC(I) where I is component number.

Note: Format used in SAAM23 is still valid -col 4-5 index I.

Col 13 - 25	Value of IC(I).

Equation entries

Relations between different IC(I) and between IC(I) and parameters, including M,U and G may be entered as equations. Such equations must be reducible to linear form to allow their solution. The definition of an IC(I) in terms of some 'dummy' adjustable P(I) permits the indirect specification of an adjustable initial condition.

Note: Although relations between IC(I) and adjustable linear parameters are permitted, their use is 'tricky' and can lead to inconsistent solutions. These relations are not recommended unless the user fully appreciates the implications. Under proper conditions they can be useful.

H STEady State

Fixed field entries

M(I) and U(I) values are entered under this heading.

Col 4 - 11	Enter U(I) or M(I) where I is a component number.
Col 13 - 25	Value of known U(I) or M(I) or on same initial estimate. (See Note below.)
Col 27 - 40	Lower limit for unknown U or M.
Col 42 - 55	Upper limit for unknown U or M.

Notes:

1. Relations between M(I), U(I) and other parameters (including IC(I)) may be entered as equations. Any M(I) or U(I) solved from such relations is automatically considered as 'known'.
2. Unless otherwise specified by the user - all U(I) are assumed to be zero and all M(I) are assumed to be unknown.
3. M(I) and U(I) entered in fixed fields cannot appear under headings other than X STE.
4. Initial estimates for M(I) and U(I) should be given whenever they are involved in the determination of initial estimates of other parameters. It is also recommended that realistic initial values be given whenever available since such estimates may greatly aid in the convergence of solutions involving non-linearities.
5. SAAM will print a diagnostic whenever the combined information entered on M(I) and U(I) is either insufficient or inconsistent. This includes fixed format entries, equations and default assignments by SAAM.
6. Although relations between U(I), M(I) and adjustable linear parameters are permitted, their use is 'tricky' and can lead to inconsistent solutions. These relations are not recommended unless the user fully appreciates the implications. Under proper conditions they can be useful.
7. No printout of M(I) and U(I) values appear in the output unless specifically asked for under X DAT (in the CATEGory field).

H STAtistical Constraints

Statistical constraints are entered as equations as follows:

g (X, M, U,IC) = h (X, M, U, IC) + OR - e

where g and h are any functions, X are parameters, and (+ OR - e) is the designation of a standard error e. The above equation may also be written as

g - h = 0 + OR - e

(Example: L(0,1)+.5*L(2.1)/K(1) = 12.2+OR-1.3)

Notes: 1. A statistical constraint may be written as a G(I) function and entered as a datum under the H DAT format.
2. When statistical information applies to a single adjustable parameter it can be entered directly on the fixed format card defining that parameter.
3. Statistical equations entered under this heading are not included in the simultaneous equations set for the solution of dependent parameters.

SOLUTION INTERRUPTS (T-INTERRUPTS)*

* At present T-interrupts are restricted to model codes 1, 2, 4, 8, and 10.

A solution may be interrupted to introduce changes in parameters and variables. The interrupts are triggered by H DAT heading cards, with TC(I) entries in columns 27-40, inserted in the H DAT input stream. The changes of variables and parameters for a particular TC(I) are entered under special interrupt headings as discussed below.

The maximum permissible number of T-interrupts is 20. The index I in TC(I) may be given any integer value from 1 to 20. TC(I) blocks are executed in ascending order of their I values. The initial block of data is, by implication, TC(0).

H DAT TC(I)

Data appearing under an H DAT TC(I) heading are treated as a block of instructions. By definition, a solution interrupt for TC(I) occurs at the largest value of T in the block preceding it (next lower TC index). The largest value of T may have been entered directly by the user or generated by SAAM indirectly through data generation or time shift requests. In going from one block to the next, the independent variable T is normally assumed to be continuous. It may, however, be reset to a new starting value by adding a card IMMEDIATELY AFTER THE HEADING CARD with an entry 'T' in the category field (col 4) and the new starting value in columns 13 - 25.

H PCC TC(I)

This heading is used to change parameter values at the T-interrupt TC(I). If X is the parameter to be changed the relation for the change may be given as

$$X(I,J) = A * X(M,N) + B$$

where X(M,N) is any other parameter (including X(I,J), and A and B are arbitrary constants. Note that a special format is used for PCC entries.

Col 2 - 3	name of parameter	(Hollerith)
Col 4 - 5	I (integer) the 1st or only subscript	
Col 9 - 10	J (integer) the 2nd subscript	
Col 13 - 25	value of A (decimal)	
Col 27 - 40	value of B (decimal)	
Col 42 - 43	name of parameter	(Hollerith)
Col 44 - 45	M (integer) the 1st or only subscript	
Col 49 - 50	N (integer) the 2nd subscript	

Notes:

1. If the name is omitted from col 2-3 it is assumed to be S, L or K and is identified from its subscripts.
2. If M and N are both zero (or blanks) and the name is omitted from col 42-43 they are set to I and J, respectively.
3. When parameter changes are given at a T-interrupt the entire set of parameter values available before the solution of the first datum in the problem are restored and then modified as indicated by the entries. ALL DEPENDENCE RELATIONS ARE INVOKED AFTERWARDS.

4. When no parameter changes are given for a T-interrupt the values of the parameters set by the preceding T-interrupt block remain in effect.
5. Parameter changes may be specified for fixed and adjustable non-linear parameters (not dependent ones) and for fixed linear parameters (not dependent or adjustable ones).

H ICC TC(I)

This heading is used to reset F(J,T) values at a TC(I) interrupt. These may be changed from the solution values at the last T value of the preceeding block to new values. The changes for each component may be entered separately or all components may be reset in the same way. No entries are required for F(I,T) that do not change.

Col 2	Enter operation code (+, -, *, /, blank, I) to indicate nature of modification. Blank means 'replace'. I means 'replace' not with the value in Col. 13-25 but with the value of TC(I).
Col 4 - 5	Component number on which modification is made. The entry of 'I' (letter I) in column 5 means that the change applies to all components.
Col 13 - 25	Value to be used in operating on F(I,T).

Note: When multiple instructions apply to the same component, the last instruction supersedes all previous ones.

H SCC TC(I)

Steady State changes at TC(I) take the form
M(I) = M(I) OP X where OP is the operation code
+, -, *, /, blank. Blank means 'replace' value of M(I) by X.

Col 2	Operation code (+, -, *, /, Blank).
Col 3	Enter U or M, whichever is appropriate.
Col 4 - 5	Index I (for M or U)
Col 13 - 25	Value of X.
Col 27 - 40	Lower limit (for adjustables)
Col 42 - 55	Upper limit (for adjustables)

Notes: 1. When steady state changes are made at a T-interrupt the values of the U and M before the solution of the first datum are restored and then modified in accordance with the instruction.
2. If no changes are given for TC(I) the steady state relations from the previous block carry over.
3. U and M may be changed from fixed to adjustable (and vice versa) at a T-interrupt.
4. For multiple instructions on the same M or U within a TC block the last one supersedes all previous ones.

H MATrix

The following format is used whenever a matrix is read in. See section II - Input Formats.

Col 3 - 4	Row dimension of matrix (integer)
Col 8 - 9	Column dimension of matrix (integer)
Col 13 - 14	Row index of first matrix element on card (integer)
Col 18 - 19	Column index of first matrix element on card (integer)
Col 21 - 32 Col 34 - 45 Col 47 - 58 Col 60 - 71	Values of consecutive matrix elements (row-wise) in E Format. (Blank is interpreted as zero).

Termination of matrix input is accomplished with a card having a '26' entry in column 3 - 4.

Note: When a matrix is read in only non-zero values are placed in the (I,J) location. Thus, an entry previously made in the (I,J) element of the matrix will remain untouched if a zero entry is given later for the same (I,J) element.

H ADD

This is a sub-heading that functions only under a regular heading. It may be used to bring in blocks of data or parameters from another problem or to repeat blocks from the same problem. In doing so the problem and its location must be identified. This information is entered as follows:

Col 1	'H' for heading
Col 3 - 5	'ADD'
Col 7 - 9	Heading name to be added
Col 13 - 25	Sequence index of heading to be added
Col 27 - 40	TC(I) of heading to be added
Col 47 - 49	Location of problem:
Col 53 - 55	Problem I.D. - initials
Col 56 - 63	Problem I.D. - number or other code. When columns 53-63 are blank, the ADD refers to the problem in which it occurs.

Cards that follow an H ADD continue behind the cards brought in by the ADD sub-heading.

H FORmat

The FORMAT sub-heading may be used to redefine the columns in which the fields of formatted information expected by SAAM are to be read from the data cards that follow. For example, 'H FORMAT (1,1,5) (3,6,9) etc.' means that field one is to be picked up from cols. 1 - 5, field 2 is blank, field 3 is in col. 6 - 9. If necessary, up to 4 FORMAT cards may be used as continuations.

H FORmat remains valid until superseded by another heading card.

NORMAL EQUATIONS

Frequently, when fitting data, it is desirable to add to the routinely generated normal equations an additional set of normal equations that represent an aggregate of previously available independent information. (For example, adding a known covariance matrix for a population to data for an individual belonging to that population.) The addition of such information, properly weighted, yields a "best" solution for the combined information. Two options are available.

Option 1: is useful in regression analysis to combine results of a previous regression analysis with new data in the present problem. Given that in the absence of independent information the normal equations generated by SAAM for the problem are $Ax = C$, the addition of another set of normal equations $A_p x = C_p$ results in a combined solution

$$(A + A_p v/v_p)x = C + C_p v/v_p$$

where v is the variance (unit weight equivalent) of the data in the problem, v_p is the variance of the data associated with the added normal equations, and x is the solution vector.

This option can also be used in non-linear iterative fitting situations with $C_p = 0$. This tends to keep the parameters in the neighborhood of their current values and damp the magnitude of the corrections.

Input:

1) Enter "1" in col 65 of card 2 of the data deck.
2) Under the heading H MATRIX add
   a) a card with the value v_p in col 21-32 (E format)(value for v is not required)
   b) matrix A_p, in matrix format, ending with a termination card ('26' in col 3-4) Note: Only one half of the symmetric matrix need be entered.
   c) C_p, entered as the first row of an N x N matrix in the matrix format ending with a '26' termination card.

Option 2: is useful in non-linear data fitting by adding parameter values (y_p) and their covariances as independent information. This results in the following composite set of normal equations:

$$(A + A_p v/v_p)x = C + A_p(y_p - y)v/v_p$$

where

A, A_p, C, v, v_p and x are as defined under Option1.

y is the vector of parameter values in the problem at the current stage of convergence

y_p is the vector of parameter values entered with the added covariance matrix.

Input:

1) Enter "2" in col 65 of card 2 of the problem deck.
2) Under an H MATRIX heading add the following:
   a) a card with v_p in col 21-32 (E format)
   b) matrix A_p, with termination card
   c) y_p as the first row of an N x N matrix with termination card.

Notes:

1. The dimension of the added matrices equals the number of primary adjustable parameters in the problem.
2. The order of the parameters in the added matrices must match the order in the problem deck.
3. The added matrices occupy "data" space. N adjustables are equivalent to (N + 1) instructions (or data points) under the H DAT heading.

S E C T I O N IV

OUTPUT

OUTPUT

Routine printout is produced for every problem deck submitted to SAAM. Special printout is added, where needed, for certain model types. Optional output is also available at the users request. This includes punched as well as printed output.

Routine printout includes:

1. A table of initial values.
2. A listing of all T-interrupts and the changes called for.
3. A listing of parameter fn-dependence.
4. A listing of the problem deck (if card 4 omitted).
5. A summary, for each iteration, of changes in primary parameter values and a set of convergence measures.
6. A table of the final solution results with values corresponding to the "best fit", estimated standard deviations for adjustable parameters and their correlation coefficients.
7. A semi-log plot of each component which has more than three data entries. (If card 4 is omitted.)

Optional printout includes items requested under OPTIONS entries (card 4).

Routine and optional outputs are described in greater detail under each of the printout headings. These are given below in alphabetic order.

Special outputs in connection with particular model types are described separately under the appropriate model types.

A MATRIX BEFORE INVERSION - Contains four partitions as shown below. In partition I are the coefficients A(I,J) of the normal equations for the primary parameters,(A * RES = CR). Partition II contains the matrix of partials of secondary parameters with respect to primary parameters. Partition III is zero. Partition IV contains the matrix of coefficients of normal equations used to calculate secondary parameters.

I	II
III	IV

Optional: Column 5, card 4.

C(I) - Denotes i^{th} component.

CARD IMAGE - A numbered listing of the problem deck, including default entries. Diagnostics detected during read-in may be interleaved.

CAT - Is the heading for the category designation of a datum.

COMP.TYPE - Is listed as 1 for a regular component, 2 for a summing component.

CONAB - Is a scaling factor for the RES vector to achieve a lower sum of squares. The value of CONAB indicates the factor by which the calculated correction vector for the adjustable primary parameters is multipled.

CONVERGENCE MEASURES - Include the improvement in the total sum of squares, the final CONAB for the iteration, and the largest fractional change in a primary parameter value.

CORRECTED SUM OF SQUARES OF PREVIOUS ITERATION - Whenever statistical constraints are given, their statistical weights are renormalized in each iteration. To compare the sums of squares of two iterations - as a test of convergence - the sum of squares of a previous iteration is recomputed with weights assigned in the current iteration.

CORRECTIONS FOR ADJUSTABLE LAMBDAS - Lists the RES vector as it will be used in the current iteration. The order is that of the adjustable primary parameters.

CORRELATION COEFFICIENTS - The matrix of correlation coefficients for primary and secondary parameters (in that order). The parameters are ordered as they appear in the final table of adjustable parameters.

COVARIANCE MATRIX - Covariances for all adjustable parameters in the order in which they appear in the final table of adjustable parameters.

Optional: column 2, card 4

CR VECTOR - Vector elements CR(I) of normal equations
A * RES = CR

Optional: column 5, card 4

D - The internal order of data entries is given as the first column of the solution table. They are ordered by T values within each block delineated by T-interrupt control cards.

FINAL VALUES - Full printout of values for the "best fit" arrived at in the run. Included is a table of adjustable parameters with their estimated standard and fractional deviations, and the matrix of correlation coefficients.

FSD - Fractional standard deviation (coefficient of variance).

INFORMATION CONNECTED WITH CALCULATION AND MODIFICATION OF RES - The RES vector as solved for from the normal equations is modified and values connected with this modification are printed in table form. (Intended as an aid in the program development).

INITIAL COMPONENT VALUES - Is a list of all non-zero initial values for the components.

INITIAL FF(I) VALUES - Is a list of all non-zero initial FF(I) values.

INITIAL VALUES - Is a table that gives, for each component, C(I), the F(I,o), COMP.TYPE, M(I) and U(I). If M(I), U(I) and F(I,o) are all zero for component I and the comp.type is "1" (regular compartment), component I is not listed.

ITERATION(I) - Intermediate printout of key information during a cycle of the iterative process towards a least squares fit. (See section VII.)

LITTLE A BEFORE MODIFICATION - Is the triangular matrix a derived from the normal equations matrix A:

$$a^T a = A$$

Optional: column 5, card 4.

LITTLE A-INVERSE BEFORE MODIFICATION - Is the inverse of "LITTLE A", a^{-1}, derived from the normal equations matrix A:

$$a^T a = A$$

Optional: column 2, card 4.

MEAN FSD -

Is mean weighted fractional standard deviation of a block of data defined for a component number with a T-interrupt block:

$$= \frac{\Sigma W(K)|(QO(K)-QC(K))/QC(K)|}{\Sigma W(K)} \quad ,QC(K) \neq 0$$

MEAN SD -

Is a mean weighted standard deviation of a block of data defined for a component number within a T-interrupt block:

$$= \sqrt{\text{NORM. SS}}$$

MODEL CODE = I ESTIMATE OF SIG FROM READ-IN DATA = X

I is the SAAM model code. If no model code is indicated by the user, (card 2) the program selects an appropriate differential equations solution method. X is the mean weighted variance of the data as defined by the information in the problem deck.

NORM. SS -

Is the normalized sum of squares of a block of data defined for a component number with a T-interrupt block:

$$= \frac{\Sigma W(K)(QO(K)-QC(K))^2}{\Sigma W(K)}$$

PARAMETER VALUES - Are listed with each solution. Those which change or are dependent are listed again at each T-interrupt.

PARTIALS OF DATA POINTS WITH RESPECT TO ADJUSTABLE LAMBDAS -

Lists, in the first two columns of the table, the component number and T-value of a datum. The remaining columns list partial derivatives of each datum with respect to each primary parameter. Each datum is given in the order in which it is stored internally. Partials for statistical contraints follow partials for the data.

Optional: column 3, card 4.

PARTIALS OF SUM OF SQUARES WITH RESPECT TO ADJ. PARAMETERS -

TOTAL SS - Gives the partial of the sum of squares for all the components with respect to each adjustable parameter.

FOR COMPONENT SS - Gives the matrix of the partial of the sum of squares for each component with respect to each adjustable parameter. The rows correspond to the parameters and the columns to the components.

Optional: column 3, card 4.

PLOT - A semi-logarithmic or arithmetic plot of the calculated and observed data. Each component which has three or more data points is plotted unless all points have identical values. In the case of the semi-log plot a) negative values will result in a diagnostic and no plot, b) off scale values are displaced by multiples of two decades to bring them onto the plot. If calculated and observed values are unequally cycled, a C is printed at the top of the graph. An asterisk, printed next to the T value indicates that the scale has been stretched at that point to separate two data, with different T values, but which would have printed on top of each other because of the limited resolution. An integer, printed at the top of the graph, records the number of data plotted at the same T value when it exceeds one. Observed values are indicated in the plot by "*" (when weighted) and "N" (when not weighted). Calculated values are indicated by "+". Coincidence of calculated and observed values (within the resolution of the printer) is indicated by "X" (when weighted) and "O" (when not weighted).

Optional: column 4, card 4.

QO - Is the heading of observed values for data entries.

QC - Is the heading for calculated values for data entries.

REORGANIZED PROBLEM INFORMATION - Includes:

1) the version of SAAM used, the number of components specified for the model, and the number of data points.
2) an expanded list of the data entries with modifications called for by control cards and with normalized statistical weights.
3) the initial values table as described above.
4) the parameter values listed as adjustable, dependent, fixed. Minima and maxima are given for adjustable parameters.
5) Fn-dependence, as interpreted by SAAM.
6) special output as called for.

Optional: column 7, card 4.

RUNNING TIME = X - Gives the time (in computer clock units) it took to run the problem.

Optional: column 1, card 1.

SIG - Is current lowest value of SIG.

SOLUTION - The first solution is considered the zero-th iteration and is based on the set of parameters initially given. A new list of parameter values is given for each T-interrupt if the values change or are dependent. Included in the output are:

1) the model code
2) SIG as estimated from the input
3) Parameter values and the table of calculated values with the headings D, C, CAT, T, THETA, K(EFF), QC, QO, QO-QC, QC/QO and WT.
4) The initial F and FP value for the following time block.
5) The normalized sum of squares, mean standard deviation, mean fractional standard deviation and sum of squares for each component in each T-interrupt block.
6) a weighted sum of squares for all the data, for each COMP and for the block of statistical constraints.
7) SIG

S.S. -
Is the weighted sum of squares of a block of data defined for a component number with a T-interrupt block:

$$= \Sigma W(K)(QO(K)-QC(K))^2$$

STARTING TIME = X - Gives the clock reading at the start of a problem.

Optional: column 1, card 1.

SUM OF SQUARES - Is printed for each solution.

T-INTERRUPT TC(I) - Gives the datum entry number, time and changes at TC(I).

TOTAL RES FOR ITERATION - The total adjustment to primary parameters made during an iteration.

VALUE AFTER ITERATION - Lists at the end of an iteration the final value for each adjustable primary parameter.

WT - Assigned weights for data.

PUNCHED OUTPUT

A-MATRIX - The diagonal and upper half of the A-matrix for adjustable primary parameters is punched out. The form used is that described under matrix entry format in the input section.

Optional: column 5, card 4.

COVARIANCE MATRIX - The diagonal and upper half of the covariance matrix for adjustable primary parameters are punched out in matrix entry format.

Optional: column 2, card 4.

CR-VECTOR - The right side of the normal equations for adjustable primary parameters is punched out as the first row of a matrix, in the matrix entry format.

Optional: column 2 or 5, card 4.

MATRIX CODE CARD - One of these cards is punched out preceding an A-MATRIX or COVARIANCE MATRIX

column 1 → 10	integer portion of problem number
column 11 → 20	code for type of matrix "1" for COVARIANCE MATRIX "3" for A-MATRIX
column 21 → 35	the value of SIG

S E C T I O N V

DIAGNOSTICS AND SAAM ERRORS

DIAGNOSTICS

The program contains a large number of internal checks which may result in diagnostic printout. If the problem calculation terminates because of an error, the program automatically proceeds to the next problem. This section contains a listing of the diagnostics printed by each subprogram. Those that cause execution of a problem to HALT are marked with an (H). The number of the subroutine that produces the diagnostic is listed at the right. Sometimes a single input error produces multiple diagnostics.

Diagnostics are prefaced by three asterisks, making them easy to find in the printout. The subroutine number is enclosed in asterisks at the end of each diagnostic.

Errors detected in compiling the program deck are printed immediately after the cards on which the errors occurred.

A DATUM SHOULD PRECEDE TC(I)	(H)	2
ALL WEIGHTS = 1. No weights were assigned to the data and the program has assigned a weight of 1. to each datum and set the number of iterations to zero.	(H)	2
CARD I HAS INVALID CATEGORY ENTRY.	(H)	2
CARD I HAS INVALID T ENTRY	(H)	2
CODE H, IN COL 57 OF CARD I INCORRECT	(H)	2
COMPONENT NUMBER NOT PERMITTED ON DG-CARD DG stands for data generation.	(H)	2
COMPONENT NUMBER (L) FOR DATUM (I) EXCEEDS N ON CARD NO. K L may not be greater than N, the number of components specified for the problem.	(H)	2
DATA LIMIT = I, EXCESS PTS. = J. CARD K GENERATED LAST PT. AT T = X, COMP = M.	(H)	2
ENTRY CONTROL CARDS INCOMPATIBLE. Relative weights for some of the data cannot be combined with absolute weights for other data.	(H)	2
ERROR, CARD I, FIELD J	(H)	2
ERROR ON CARD I. DO NOT ENTER T IN FIELD 2, T-VALUE IN FIELD 3.	(H)	2
NO DATA GIVEN No entries under H DAT. At least one is required.	(H)	2
NO DATUM PRECEDING DG-CARD A data generation card picks up category, component no. etc. from the preceding entry.	(H)	2
SUBSCRIPT I OR J FOR CATEGORY X EXCEEDS N	(H)	2
SUBSCRIPTS IGNORED FOR CATEGORY X		2
T-INTERRUPTS EXCEED I. I is the maximum number of t-interrupts permitted	(H)	2

TOO MANY COMPONENTS IN MODEL.	(H)	2
I TOO MANY PARAMETERS IN MODEL	(H)	3
L(0,1) ADDED AS A DUMMY		3
MAX. NUMBER OF PARAMETER NAMES IS I	(H)	3
NO FIELD NAMED X FOR PARAMETER Z	(H)	3
NO PARAMETERS HAVE BEEN ENTERED	(H)	3
SUBSCRIPT OF X(I,J) INCORRECT. MAX VALUE GIVEN IS K.	(H)	3
X(I,J) NOT IN LIST BUT FIELD DEFINITION USED	(H)	3
XX NOT IN DICTIONARY	(H)	3
ERROR IN FUNCTION DEPENDENCE CODE FOR X(I,J)	(H)	4
FIELD X UNDEFINED. SOME G(I) NOT CALCULABLE G(J) entered in field X cannot be calculated.	(H)	4
LIST OF SIMULTANEOUS DEPENDENCE EQUATIONS EXCEEDS STORAGE The maximum number is 55. This includes explicitly defined equations which must be included to satisfy the dependence relations.	(H)	4
M (OR U) IN FIXED FORMAT MUST BE ENTERED UNDER H STE	(H)	4
NO. OF EQUATIONS OR NAMES FOR FIELD X EXCEEDS STORAGE	(H)	4
OVERFLOW IN STORING EQUATION TERMS OR VALUES	(H)	4
PARAMETER (I,J) IN ERROR. ONLY Z OR K MAY BE ENTERED IN FIELD L	(H)	4
STORAGE INSUFFICIENT FOR G(I) = I(J,T) This equation is being generated because a parameter is fn-dependent on a F(I).	(H)	4
X(I,J) SUBSCRIPT EXCEEDS 25	(H)	4
PARTIALS OF PARAMETERS W.R.T. ADJUSTABLE S AND K EXCEED STORAGE W.R.T.=with respect to. The number of adjustable S(I,J)and K(I) or the number of parameters dependent on them must be reduced.	(H)	5

TC(I) DEPENDENCE EQUATIONS DEFINE X(I), I=1, ...,N An M(I) or U(I) defined by dependence relations will not be considered an unknown in the steady state calculation.		5
ERROR IN EQUATION I UNDER STAT. INFO.	(H)	7
STANDARD DEVIATION MUST BE NON-ZERO IN STAT. INFO.	(H)	7
STATISTICAL CONSTRAINTS + DATA EXCEED I. The number of data entries <u>plus</u> the number of statistical constraints is limited to a maximum of I.	(H)	7
THE L MATRIX IS SINGULAR Steady state calculation cannot proceed because the L matrix cannot be inverted.	(H)	8
THE STEADY STATE MATRIX IS SINGULAR The matrix of L's and constraints cannot be inverted.	(H)	8
OVERFLOW STORING EQUAT. DEFINING M(I) OR F(I) Equation are generated to define M(I) or F(I) for SUMMERS.	(H)	9
2-ND SUBSCRIPT OF X(I,J) OUT OF RANGE	(H)	12
DEGREES OF FREEDOM LESS THAN 3 The number of weighted data points minus the number of adjustable L(I,J) is less than 3. The solution will proceed if error estimates (SD,FSD,etc.) have been entered for the data.	(H)	12
DT (I) CANNOT BE DEFINED BY AN EXPLICIT F(I,T) EQUATION	(H)	12
DO NOT ENTER IC(I), UF(I), FF(I) FOR SUMMING COMPONENT	(H)	12
I ADJUSTABLE PARAMETERS GIVEN. J PERMITTED	(H)	12
ITERATIONS SET TO ZERO An error has been detected and iteration is not carried out.		12
L(I,J). NEITHER SUBSCRIPT MAY REFER TO A SUMMER	(H)	12
S(I,J). ONLY 1ST SUBSCRIPT MAY REFER TO A SUMMER	(H)	12

X(I) CANNOT HAVE SUMMER SUBSCRIPT (H) 12

X(I,J) HAS NOT BEEN DEFINED BUT HAS BEEN REQUESTED BY DATUM J (H) 12

X(I,J) IS NOT A KNOWN PARAMETER (H) 12
The name X(I,J) has been used in an equation but has never been defined.

X(I,J) MAY NOT BE FN-DEPENDENT (H) 12
S(I,J) and K(I) may not be function dependent.

X(I,J). SUBSCRIPT = 0 OR EXCEEDS NO. OF COMPS. (H) 12

X(I,J) = Y IS OUTSIDE LIMITS OR LIMITS ARE INCORRECT 12
An upper or lower limit is violated or the lower limit is greater than the upper limit. If it is a primary parameter a zero iteration calculation is performed.

X(K) MAY NOT BE AN ADJUSTABLE PARAMETER USE DEPENDENCE ON DUMMY P(I) OR L(I,J) (H) 12

DATUM I UNCALCULABLE, L(J,L) WAS NOT ENTERED (H) 13
R(I,J) cannot be calculated since L(I,J) was not entered.

DF(I) MAY BE DEFINED ONLY FOR SUMMING OR DEFINED F(I,T) (H) 13

AN ASTERISK APPEARS IN F.S.D. COLUMN WHEN F.S.D. SQUARED IS NEGATIVE. 14
This is the result of numerical errors in inverting ill-conditioned matrices of normal equations coefficients.

AN 'F' INDICATES THAT QC WAS RECALCULATED AFTER FINAL S AND/OR K VALUES WERE DETERMINED. 14

AN '*' FOLLOWS QC WHEN A DATUM DETERMINES AND INCORPORATES THE FINAL VALUE OF S AND/OR K. 14

MODEL CODE HAS BEEN CHANGED TO 10, 2 NOT SUITABLE FOR THIS MODEL 17

ONLY MODEL CODES 1 AND 8 PERMIT FN-DEPENDENT L(I,J) (H) 17

ONLY MODEL CODES 1, 8 AND 10 PERMIT DELAY COMPONENTS (H) 17

PROBLEM HAS FUNCTION DEFINITIONS WHICH ARE AVAILABLE ONLY IN MODEL CODES 1, 8 AND 10 17

DATUM I HAS T VALUE (X) LESS THAN T VALUE (Y) AT START OF TC(J). (H) 18

J ADDITIONAL POINTS IN TC(I) HAVE T VALUE LESS THAN T VALUE (X) AT START OF TC(I)	(H)	18
ALL WEIGHTS = ZERO, FOR COMPONENT I If K(I) or S(I,J) are adjustable other weighted data are used to calculate them.	(H)	19
CALCULATION OF WEIGHTS FOR STATISTICAL CONSTRAINTS REQUIRES ESTIMATE OF ABSOLUTE DEVIATION OF DATA	(H)	19
DF(I) MAY BE DEFINED ONLY FOR A SUMMER(I) OR AN EXPLICITLY DEFINED FF(I)	(H)	19
ESTIMATE OF ABSOLUTE DEVIATION OF DATA NEEDED. The degrees of freedom are less than 3 and calculation cannot proceed without some error estimates (e.g. SD,FSD,etc.) for data.	(H)	19
ITERATIONS SET TO ZERO An error has been detected which makes iteration impractical or impossible.		19
NO ADJUSTABLE L(I,J). ITERATIONS SET TO ZERO. If there are no adjustable L's or P's the number of iterations is set to zero.		19
NO DEFINITION GIVEN FOR X(I) X(I) has been used in an equation under H DAT but has not been defined by an equation.		19
THE SUBSCRIPTS OF L(I,J) ARE DUPLICATED BY ANOTHER PARAMETER	(H)	19
DEP. EQUATION I REDUNDANT DEFINING X(I,J)	(H)	20
DEP. EQUATIONS NOT SOLVABLE	(H)	20
DEPENDENCE STORAGE EXCEEDED Rearranging the order of dependence equations may relieve this problem if some can be solved ahead of others.	(H)	20
DEP. EQUATION I INCONSISTENT DEFINING X(I,J) Inconsistency with preceding information.	(H)	20
I MORE INDEPENDENT EQUATIONS NEEDED. J UNKNOWNS UNSOLVED The list of J unknowns follows this dependence diagnostic.	(H)	20
INSUFFICIENT STORAGE FOR STEADY STATE EQUATIONS	(H)	20

M(I), (OR U(I)) DEFINED BY UNKNOWN M AND/OR U BUT M(I), (OR U(I)) WAS NOT ENTERED AS AN UNKNOWN	(H)	20
STEADY STATE EQUATIONS MUST BE LINEAR IN UNKNOWN M AND/OR U	(H)	20
T AND F NOT PERMITTED IN DEPENDENCE EQUATIONS Dependence relations are calculated using initial estimates. T and F may be used in Fn-dependence.	(H)	20
XXXX UNDEFINED BY THE INPUT No formatted card or equation for XXXX has been entered.	(H)	20
VALUES SAVED TO RECALCULATE DATA NON-LINEAR IN ADJ. S AND/OR K EXCEED STORAGE Data non-linear in adj. S and/or K require excess storage.	(H)	22
RATIO OF CALCULATED SIGMA TO ESTIMATED SIG = X, ITERATIONS SET TO ZERO The deviation of the calculated from the observed values is more than ten times greater than derived from the input estimate of the errors. Better initial estimates of parameters or larger estimated standard deviations of data are needed.		29
CARD I ENTRIES CANNOT BE USED.	(H)	32
CARD I HAS ERRORS.	(H)	32
CARD I, HEADING H xxx, CALLS FOR TC(J), H DAT TC(J) NOT IN DECK. An H DAT TC(J) heading is required to set the time of TC(J).	(H)	32
CARD (I) ILLEGAL EQUATION T-interrupt changes must be in fixed format.	(H)	32
H XXX TC(I) GIVEN BUT NO TC(I) IN DATA	(H)	32
NO TC(J) ENTERED ON CARD (I), HEADING X Heading X must be associated with some T-interrupt.	(H)	32
U or M NEEDED ON CARD I	(H)	32
X(I,J) IS DEPENDENT AND MAY NOT BE CHANGED AT PCC TC(K)	(H)	32
X(I,J) NOT IN LIST OR SUBSCRIPTS ARE INCORRECT AT PCC TC(K)	(H)	32

X(I,J) MAY NOT BE CHANGED AT TC(K) SINCE ADJ S AND
K MAY NOT BE CHANGED AT T-INTERRUPTS. (H) 32

X(K,M), TC(I), A COMPONENT NO. IS GT J (H) 32
J is the number of comps in the model. An entry under a t-interrupt heading has used a subscript greater than J.

CORRELATION MATRIX NOT CALCULABLE 41
The covariance matrix could not be calculated.

ERROR IN RECOVERY OF VALUES FOR RECALC. OF DATA (H) 40

COVARIANCE MATRIX IRREGULAR 41
Negative diagonal elements resulting from inversion of ill-conditioned matrices may cause this diagnostic.

NO STEADY STATE SOLUTION EXECUTED FOR TC(J) BECAUSE
THERE ARE I TOO MANY (OR TOO FEW) INDEPENDENT M AND/OR
U CONSTRAINTS (H) 42

PARTITION I OF THE MATRIX IS SINGULAR. THE FOLLOWING
ADJUSTABLE PARAMETERS ARE INVOLVED. (H) 44
Symmetric matrices are partitioned into independent blocks for inversion. A partition involving the listed parameters is singular. At least one of the parameters in this block is dependent.

ZERO DIAGONAL ELEMENTS MATRIX IS SINGULAR (H) 44
One or more diagonal elements of the symmetric matrix being inverted is zero.

ERROR IN WRITING (READING) COMMON (H) 50
The NTRAN copy has failed.

NON-LINEAR STEADY STATE FAILS TO CONVERGE IN I
ITERATIONS 50
The attempt to calculate M and/or U values by iteratively adjusting dependent L's has failed.

NON-LINEAR STEADY STATE SOLUTIONS ARE LIMITED TO A TOTAL OF 25 UNKNOWN M'S AND U'S. THE SET OF CONSTRAINT EQUATIONS MUST, AS IN INDEPENDENT SET, YIELD SOLUTIONS FOR J MORE M'S AND/OR U'S (H) 50

SINGULAR MATRIX CALCULATING RES FOR M AND U (H) 50
Set of equations for the solution of M and U are inadequate. (dependent set)

STEADY STATE CONVERGED IN I ITERATIONS 50
I iterations were needed to calculate M and/or U values by iteratively adjusting dependent L's.

DIAGNOSTICS PRINTED ABOVE MAY BE SPURIOUS WHEN ERRORS HAVE BEEN DETECTED IN THE CARD IMAGES (H) 53
The program has attempted to continue its scan 54
of input after an error was detected.

NAMES ENTERED + THOSE GENERATED BY SAAM EXCEED THE CURRENT LIMIT OF 200 (H) 53

DN(I) MAY NOT BE DEPENDENT ON ADJUSTABLE S AND/OR K (H) 54

AT T = X, L(I,J)*X SET = 1.069 E13 56
An exponent, L*t, has exceeded 30. and has been set equal to 30. Model code 2.

COMP (I) ISOLATED FOR STEADY STATE CALC. SINCE L(I,I) = 0. 57

MATRIX SINGULAR. (H) 57
The matrix used in the solution is singular. Model Code 3.

L70/L60 CODE ON CARD I = J IS IMPROPER 64

AMT. IN COMP(I) GT + E15 AT T=X SOLVING FROM T=W TO T=Y, TC(J). (H) 65
THE CURRENT EFECTIVE VALUES OF L(I,J) AND COMPS FOLLOW.
The solution method yields component values which are greater than E15.

COMMON VECTOR WRITTEN ON UNIT 21 65

TOO MANY STEPS TO SOLVE FROM T=X TO T=Y AFTER TC(I) USING MODEL CODE J. (H) 65
This limit may be overwritten by increasing the factor in col 2 - 11 of card 3 (by default it is 1). Examine data for errors, $\sum_j L_{ij}$ very large, very high T values or delay elements with excessively fine resolution.

ERROR: OVERFLOW (LOG OR SQUARE ROOT OF NEG. VALUE, DIVISION BY ZERO, NEG. VALUE TO NON-INTEGER POWER, LOG OF 0) WHILE CALCULATING X(I) (H) 66

TOO MANY NESTED G(I) CALCULATING X(J). (H) 66
The program has insufficient buffer area to resolve the solution of nested G's.

NO ADJUSTABLE PARAMETERS. 67

DATA DELETED FOR T = X 68
The data for T given by the diagnostic are incomplete and all data having time T=X have been dropped from the data list. Model Code 5.

DATA INCOMPLETE 68
Some information in the data list is missing. A complete set of observations must be entered as data at each t. Model Code 5.

DATA INSUFFICIENT. (H) 68
There are not enough data given (correctly) to continue the solution. Model Code 5.

ERROR: AMT= X, DELTA T = Y, KJ = I (H) 70
Modification of shift elements not yet available.

STORAGE EXCEEDED BY OPER. STRING FOR SUMMERS (H) 75

INSUFFICIENT STORAGE FOR EQUATION STRING (H) 76
The storage space for equation terms has been exceeded.

DT(I,J) = 0 (H) 77
An adjustable or fn-dependent delay time has become zero.

FN-DEP OPERATION CODE ERROR (H) 80

LOG PLOT IS IMPOSSIBLE - ALL ABCISSA (ORDINATE) VALUES <0 84

NO PLOT - ABCISSA (ORDINATE) RANGE OF VALUE = ZERO 84
Plot will be omitted.

THE FORMAT BEING GENERATED FOR THE PLOT (BY SAAM) EXCEEDS STORAGE (H) 85
Plotting is done by building a single variable format for each plot. Too much information has been incorporated in a request for a single plot.

K(I) CANNOT BE ADJ SINCE S(J,I) IS ADJ. (H) 87

WARNING: INITIAL ESTIMATES SHOULD BE GIVEN FOR ADJ. S OR K ON WHICH S OR K DEPEND 87

WARNING: K(I) AND/OR S(I) MAY BE INCOMPATIBLY DEPENDENT ON ADJ. S AND/OR K 87

OVERFLOW STORING XXXX INFORMATION IN INPAR (OR INCOMP) VECTOR (H) 88
Detailed information about parameters (components) is sorted into INPAR (INCOMP) for use by solution routines.

I-O UNIT ASSIGNMENT NEEDED FOR SCRATCH USE STOP 8 indicates that the I-O scratch assignment for pre-read output, NTAPE9, is undefined in SAAM, the main program.	(H)	89
ADDING ELEMENT (I,J) EXCEEDS STORAGE	(H)	92
ADDING ELEMENT (I,J) EXCEEDS TIMETABLE STORAGE.	(H)	92
DN(I) OMITTED OR IS LESS THAN 2	(H)	92
SOLUTION OF SHIFT ELEMENT MUST USE SLOW METHOD DUE TO INSUFFICIENT SCRATCH SPACE		92
DIVIDING BY ZERO A T-interrupt error.	(H)	95
AT MATRIX OVERFLOW. The storage of information has exceeded the available storage locations. Model Code 3.	(H)	97
DATA STORAGE EXCEEDED. Information is stored jointly with the partials matrix. This diagnostic results when the space is insufficient to store all the information given. Model Code 3.	(H)	97
FUNCTION INPUT ERROR. Model Code 3.	(H)	97
FUNCTION X NOT IN DATA. Model Code 3.	(H)	97
MATRIX AND/OR STEADY STATE INFO NEEDED	(H)	97
MATRIX INPUT ERROR. The matrix input is incorrectly punched. Model Code 3.	(H)	97
TOO FEW STEADY STATE EQUATIONS. The number of equations must be equal to the number of components. Model Code 3.	(H)	97
TOO MANY STEADY STATE EQUATIONS The number of equations must be equal to the number of components. Model Code 3.	(H)	97
A L(O,I) MUST BE ENTERED FOR EACH PARAMETER	(H)	98
AT-MATRIX STORAGE OVERFLOW Matrices and related information have exceeded the available storage. Model Code 11.	(H)	98
DATA INCORRECT	(H)	98

DATA INDIV. I INCOMPLETE. Data giving the values for individual I are missing. Model Code 11.	(H)	98
MATRIX I.D. FOR INDIV. I INCOMPLETE. The information on the card preceding a matrix has one or more entries missing. Model Code 11.	(H)	98
MATRIX N.G. FOR I. The matrix input for individual I is incorrectly punched. Model Code 11.	(H)	98
NO. OF INDIVIDUALS LESS THAN OR = 1	(H)	98
STD. DEVS. FOR I GIVEN WITH MATRIX FOR J. See manual for model code 11 input instructions.	(H)	98
DT(I) INITIALIZATION FAILS	(H)	102
MATRIX INPUT INCORRECT. The matrix reading routine has found the matrix dimensions, as punched, incompatible either with the dimensions of the matrix required by the problem, or with the subscripts of a matrix entry, as punched.	(H)	103
ARGUMENT OUTSIDE PERMISSIBLE RANGE OF VALUES	(H)	108
DIVISION BY ZERO In solving set of simultaneous dep. relations.	(H)	108
EQUATION I INCONSISTENT	(H)	108
EQUATION I REDUNDANT	(H)	108
LOG. OF NEG. NO. CALLED FOR During solution of dependence equations.	(H)	108
NON-LINEAR TERM	(H)	108
OPERATION NOT AVAILABLE. An operation code in an equation is incorrect in solving parameter dependence equations.	(H)	108
OPERATION X CANNOT BE CARRIED OUT IN EQUATION I	(H)	108
X(I,J) NOT IN LIST OF UNKNOWNS AND NOT CALCULABLE	(H)	108
EQUATION I IS REDUNDANT The solution proceeds although a redundancy exists.		109
INCONSISTENT SET OF EQUATIONS Simultaneous solution of dependence equations reveals an inconsistent set.	(H)	109

R(I,J) IS USED IN AN EQUATION BUT L(I,J) WAS NOT ENTERED (H) 115

SUBSTITUTING L(I,J)*M(J) FOR R(I,J) EXCEEDS STORAGE (H) 115

EQUATION FOR I-TH F, UF OR DF UNCALCULABLE AT T = X (H) 118

M(I) = X DEFINED BY INPUT EQUATIONS 121
This printout lists the M(I) that are determined directly from the input equations, before the steady state solution is carried out.

U(I) = DEFINED BY INPUT EQUATIONS 121
This printout lists the U(I) that are determined directly from the input equations, before the steady state solution is carried out.

DN(I) MAY NOT BE DEPENDENT ON ADJ. PRIMARY PARAMETERS
OR UNKNOWN U OR M (H) 122

WARNING SEE MANUAL AN M, U, OR IC IS DEPENDENT ON
ADJ. S OR K 122
Inconsistencies between printed solution and parameter values may occur. See discussion in section III of the manual.

PAR(I,J) EXCEEDS 10E30 AND SET=10E30, ITERATIONS=J 125
J is the current iteration.

DATA DEPENDENT ON UNCALCULABLE COMPONENTS HAVE NO
MEANINGFUL VALUES 126

IF SUCCESSORS EXIST, NO INITIAL VALUES CAN BE PASSED
FROM COMPONENTS I,J---K 126

T-INFINITY SOLUTION FOR COMPONENTS I,J...K 126
a) IS UNRESOLVABLE
b) IS INFINITE
c) FAILS DUE TO SINGULAR MATRIX
d) FAILS TO CONVERGE
e) IS NOT CALCULABLE
f) UNCALCULABLE. INPUT TO COMP. M NON-CONVERGENT IN L STEPS.

DATUM(I) AT TIME X HAS A T-VALUE LESS THAN THE
T-VALUE, Y, AT TC(J) (H) 128
Within each T-interrupt block the T values must be greater than the initial T=Y of the block (T can be reset if necessary).

MODEL CODE I INCORRECT (H) 128

ERROR IN PUNCH ARGUMENT LIST 133

SIG = 0. RES. NOT MODIFIED 134
The parameter correction vector,RES, resulting from solution of the normal equations could not be modified because no error estimates were entered for data. The solution continues with the unmodified RES.

AT-MATRIX OVERFLOW. ITER. SET TO ZERO 135
Storage space for added matrix is insufficient. Only the initial solution is made, and without the matrix information.

ERROR IN MATRIX READ-IN. (H) 135
The matrix supplied as additional information under special options (card 2) has been punched incorrectly.

DATUM I, SA(J) UNCALCULABLE. M(J)=0. (H) 142

DATUM (I), DERIVATIVE OF XX(I,J) AT T=Y, TC(K) UNCALCULABLE (H) 142

DELAY COMPONENTS MAY NOT BE INTRODUCED AT T-INTERRUPTS. COMP(I) AT TC(J) IN ERROR (H) 144

DIVISION BY ZERO FOR DELAY COMP.(I) AT TC(J) (H) 144

MEAN TIME FOR DELAY COMP(I) AT TC(J) LESS THAN OR EQUAL TO ZERO (H) 144

SHIFT(I) CANNOT BE DROPPED AT TC(J). (H) 144

INSUFFICIENT STORAGE TO SAVE STRINGS AT T-INTERRPUTS (H) 145

ALL LOSSES FROM SHIFT ELEMENT (I,J) = 0 (H) 148

A FUNCTION XX(I) UNSOLVABLE (H) 151

NESTING OF FUNCTIONS IN X(I) EXCEEDS STORAGE. (H) 151
Testing for dependence on adj. secondary parameters.

I EQUILIBRIUM SUBSYSTEM(S) FAILED TO CONVERGE IN J TRIES AT T=X (H) 152
The F(I,J) values for the last two tries are printed.

THE EQUILIBRIUM CONSTANT L(I,J) AT T=X IS INCONSISTENT (H) 152

THE EQUILIBRIUM SUBSYSTEM WITH COMP(I) IS NON ZERO BUT THE SUM OF THE COMPS IS ZERO AT T=X (H) 152

THE EQUILIBRIUM SYSTEM WITH COMP(I) IS INDETERMINATE AT T=X (H) 152

DT(I,J) = 0. AT T=X (H) 159

PREC SET = 1., MUST BE LESS THAN OR EQUAL TO 1. 159
PREC is a precission factor for the salution of diff. eqn.

INSUFFICIENT STORAGE FOR INPUT VECTORS (H) 163
These are input vectors generated internally by SAAM to permit TINF solution.

AN UNDEFINED NAME CODE HAS BEEN USED. X (H) 166

ERROR IN INPUT DETECTED IN SUBROUTINE I (H) 166
SUBCRIPT ERROR (H) 166
In trying to store a name.

THE NAME X IS NOT PERMITTED (H) 166

A NAME IS GREATER THAN 24 CHARACTERS (H) 170
Dictionary names as they appear in the internal table can have, at most, six 4 character words.

LAST ENTRY IN STORAGE IS -X- THE ENTRY OF -Y- WOULD EXCEED STORAGE (H) 171
The number of different names used in a problem plus those generated internally by SAAM exceeds 200.

BUFFER SIZE EXCEEDED (H) 172
The buffer used in interpreting input is overflowing. Can you eliminate redundant information?

ERROR CARD I. (H) 172

ERROR FOUND ON CARD I BY SUBROUTINE 166 (H) 172
Entry EQTEMP (NDTEMP), Heading is y
EQTEMP builds a buffer from equations.
NDTEMP builds a buffer from formatted entries.

ERROR FOUND ON CARD I BY SUBROUTINE J, ENTRY X, HEADING IS Y. (H) 172
The entry NDTEMP reads all cards in parameter format, EQTEMP reads all equation entries.

ERROR IN POSTAP (H) 174
The subroutine that positions scratch files has encountered difficulty.

DL AND RS MAY NOT BE MIXED WITH DT AND DN (H) 183

NAME CHANGES: DT USED FOR DL, DN USED FOR 1./RS 183

X(I) ENTERED BUT NO Y(I) (H) 183
X and Y may be either DT or DN.

ORDINATE VALUES DO NOT PERMIT LOG/LOG PLOT OF C(24) VS C(25)		188
THE FOLLOWING CARDS HAVE ENTRIES OUTSIDE THE FORMATTED FIELDS		249
This is a warning that some characters in the input are being ignored because they are outside the fields defined for formatted input.		
ADDING PARENTHESES (TO FACILITATE INTERNAL ORGANIZATION OF AN EQUATION) EXCEEDS THE MAX. OF I PAIRS	(H)	266
EQUATION TOO LONG FOR AVAILABLE STORAGE AFTER ADDING PARENTHESES INTERNALLY	(H)	266
PARENTHESES INCORRECTLY PAIRED	(H)	266
EQUATION EXTENDS BEYOND COL. 55	(H)	267
POSSIBLE ERROR ON CARD I	(H)	267
A FUNCTION, OPERATION OR NAME IS INCORRECT PRECEDING PARENTHESIS I	(H)	277
A PROBLEM CANNOT REFERENCE ITSELF ON CARD 2	(H)	277
A SUBHEADING MUST BE PRECEDED BY A HEADING	(H)	277
BEGINNING OF FIELD G.T. END	(H)	277
CARD TO BE DELETED DOES NOT MATCH ANY CARD IN THIS CATEGORY	(H)	277
CATEGORY IS NOT PRESENT IN ABOVE PROBLEM	(H)	277
CLOSED PARENTHESIS MISSING	(H)	277
END OF FIELD G.T. 72	(H)	277
EQN CONTINUATION MISSING	(H)	277
EQNS EXPLICIT IN FF AND DF ALLOWED ONLY UNDER H DATA	(H)	277
ERROR IN FIELD I	(H)	277
FIELD INDEX TOO HIGH	(H)	277
FORMAT SPECIFICATION INCOMPLETE	(H)	277
INCORRECT ENTRY	(H)	277
INCORRECT NUMBER	(H)	277
INCORRECT SUBSCRIPT	(H)	277

I-TH CLOSED PARENTHESIS MISSING	(H)	277
I-TH EQUAL SIGN SHOULD DEFINE A SUBSCRIPT	(H)	277
I-TH OPEN PARENTHESIS MISSING	(H)	277
LIBRARY OR INPUT TAPE NOT DEFINED	(H)	277
MORE THAN 10 SUBSCRIPTS DEFINED	(H)	277
MUST SPECIFY INP, OUT, OR LIB	(H)	277
NAME EXCEEDS 6 CHARACTERS	(H)	277
NO PROBLEM I.D. GIVEN	(H)	277
NUMBER G.T. 2**17	(H)	277
NUMBER G.T. 10**38	(H)	277
ONLY FF, G, UF AND DF EQUATIONS MAY BE DEFINED UNDER H DATA OR WITH X IN COL. 1	(H)	277
OPEN PARENTHESIS MISSING	(H)	277
OPERATION AT BEGINNING OF EQUATION OR PARENTHESIS	(H)	277
OPERATION HEIRARCHY AMBIGUOUS	(H)	277
OPERATION SIGN MISSING	(H)	277
PARENTHESIS EXCEED MAX. OF I	(H)	277
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PROBLEM CALLS FOR SA X	(H)	277
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PROBLEM REQUESTED (BY CARD 2 ENTRY) IS NOT AVAILABLE	(H)	277
PROBLEM TO BE MODIFIED CANNOT BE LOCATED	(H)	277
PROBLEM TO BE MODIFIED IS VOID	(H)	277
STAT. INF. INCORRECT	(H)	277
SUBSCRIPT DEFINITION INCORRECT	(H)	277
SUBSCRIPT EXCEEDS 99	(H)	277
SUBSCRIPT VECTOR SPACE EXCEEDED	(H)	277

THe 5-TH CARD MUST BE A HEADING	(H)	277
TOO MANY CARDS IN THE DECK	(H)	277
TOO MANY EQN. CARDS	(H)	277
TOO MANY EQUAL SIGNS	(H)	277
TOO MANY FORMAT CARDS	(H)	277
TOO MANY ERRORS IN DECK	(H)	277
TOO MANY HEADING CARDS	(H)	277
TOO MANY HEADING CATEGORIES	(H)	277
TOO MANY OTHER PROBLEMS CALLED FOR	(H)	277
TOO MANY SUBSCRIPTS	(H)	277
TOO MANY TERMS NEEDED	(H)	277
TOO MANY UNDEFINED NAMES	(H)	277
TWO OPERATION SIGNS TOGETHER	(H)	277
X IS NOT A FUNCTION	(H)	277
X IN A NUMERICAL FIELD	(H)	277
X IS NOT A VARIABLE	(H)	277
X NOT AN ACCEPTABLE REFERENCE	(H)	277
X NOT IN DICTIONARY	(H)	277
X TOO MANY UNDEFINED NAMES	(H)	277
ZERO FIELD NOT ALLOWED	(H)	277
Z IS NOT AN ACCEPTABLE ENTRY IN COL. 1 The entry X_ _ _ (I etc. is not permitted).	(H)	277
+ OR - INCORRECTLY ENTERED	(H)	277

DETECTED ERRORS IN THE SAAM PROGRAM AND THEIR STATUS

1976

1. Discovered — April 17, 1976 | In SAAM — Since SAAM26, 1974 | Corrected — July 13, 1976
An explicit equation name entered as an operand in a term of a parameter dependence relation was not added to the simultaneous set. Nesting of equations (defined with an X in col. 1) in dependence relations is now correctly handled.

2. Discovered — April 1976 | In SAAM26 and SAAM27 — Since Aug. 1975 | Corrected — July 13, 1976
If the last T-interrupt block for a component contained only one datum, the plot routine failed to plot it as a separate plot segment.

3. Discovered — May 1976 | In SAAM27 — Since Oct. 1975 | Corrected — July 7, 1976
The successors of delay components were calculated by a new method which contained an error. This caused erratic behavior in the solution.

4. Discovered — Aug. 1976 | In SAAM — Since SAAM24 | Corrected — Sept. 8, '76--SAAM27
An error in SAAM's compiler caused it to set up an incorrect internal string for equations with several terms when a term contained division followed by multiplication.

5. Discovered — Aug. 1976 | In SAAM — Since SAAM27 | Corrected — Aug. 10, '76--SAAM27
Storage overlap caused error in calculation of minimum step size in Model Codes 1, 8, 10. This resulted in too long a calculation time and occasionally a diagnostic of 'TOO MANY STEPS' in calculation.

6. Discovered — Sept. 1976 | In SAAM — Since SAAM27 | Corrected — Oct. 13, '76--SAAM27
Delay components are not yet correctly handled by Model Code 1 in SAAM27.

7. Discovered — Dec. 8, 1976 | In SAAM — Since SAAM27 | Corrected — Dec. 14, '76--SAAM27
Delay components do not observe the conservation principle when more than two integration steps are necessary to cover the time (DT(I)/DN(I)) for a delay step.

1977

8. Discovered Jan. 10, 1977 — In SAAM Since SAAM27 — Corrected Jan. 13, 1977
LOG(X), SIN(X), COS(X) compiled incorrectly and gave incorrect results.

9. Discovered Jan. 31, 1977 — In SAAM Since SAAM27 — Corrected Feb. 18, 1977
Calculation of a delay fed by a delay was incorrect.

10. Discovered March 1977 — In SAAM Since SAAM27
Some problems which include function dependent equilibrium parameters fail to calculate correctly.

11. Discovered May 20, 1977 — In SAAM Since Dec. 10,'76 — Corrected May 26, 1977
Occasional failure of control card to modify T, TH or QO by a G function.

12. Discovered May 20, 1977 — In SAAM Since SAAM25 — Corrected May 26, 1977
G(40) fails to modify a parameter when used in the function dependence field.

13. Discovered Jul. 5, 1977 — In SAAM Since SAAM27
Incorrect printout of initial component values was observed in one problem (in the table of Final Values). It did not affect the solution.

14. Discovered Aug. 16, 1977 — In SAAM Since SAAM27 — Corrected Aug. 22, 1977
A problem which included T-interrupts had an incorrect plot. The plot for the last component was stretched out. This occurred when the last datum was assigned to the last component to be plotted and its T-value was smaller than a previous T-value in the problem.

15. Discovered Dec. 16, 1977 — In SAAM Since Jun '77 — Corrected Dec. 1977
The normalization of the weights of data entries was incorrect when there were adjustable primary parameters.

16. Discovered Dec. 21, 1977 — In SAAM Since SAAM27 — Corrected Feb. 1, 1978
Equilibrium subsystem calculations not always reliable.

17. Discovered Jan. 1, 1978 — In SAAM Since SAAM27
Solution time with delay elements may become excessive as delay time decreases.

S E C T I O N VI

MODEL TYPES

MODEL TYPES IN PROGRAM LIBRARY

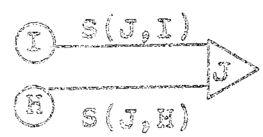
Different types of models can be processed by SAAM. Each type has a code that may be called for in a problem. To simplify the preparation of data, common nomenclature and data input forms have been adopted for all types of models, and equivalences are defined between the particular parameters of the model type and the program nomenclature. Operational and schematic notation is also used as an aid in describing the equivalences.

Each model type generates a set of functions F(I,T). Through the use of the coefficients K(I) and S(H,J) and other equations (e.g., G-functions) more complex functions, QC(H,T), can be generated.

SCHEMATICS FOR COMPARTMENTAL MODELS

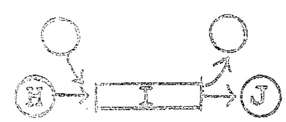
Program Element	Description	Symbol
T	Independent variable	
TH	Second independent variable	
F(I,T)	Compartment function	I
FF(I,T)	Compartment forcing function	$\boxed{I}$
IC(I)	Value of F(I,T) at start of solution	$I \leftarrow *IC(I)$
UF(J,T)	Input function for component J	$\xrightarrow{UF(J)} J$
L(J,I)	Rate coefficient	$I \xrightarrow{L(J,I)} J$
S(K,I)	Summing coefficient	$K \xleftarrow{S(K,I)} I$
K(I)	Proportionality constant	$I \lhd$ K(I)
QC(J,T)	Linear combination of the F(I,T), For SUMMER J.	

$$QC(J,T) = K(J)*\sum_{I} S(J,I)*F(I,T)$$



Generator of Function F(J,T) $\boxed{J}$

Delay component



Model Codes 1, 2, 8 and 10 - Common features

ORDINARY LINEAR AND NON-LINEAR DIFFERENTIAL EQUATIONS

COMPARTMENTAL MODEL

This model type defines F(I,T) as solutions of ordinary linear and non-linear differential equations and is directly applicable to compartmental models. (See model codes 1, 2, 8, 10.)

The general format for differential equations is

$$dF(J,T)/dT = \sum_{\substack{I=1 \\ I\neq j}}^{N} \tilde{L}(J,I)*F(I,T) - \sum_{\substack{I=0 \\ I\neq j}}^{N} \tilde{L}(I,J)*F(J,T) + UF(J)$$

(For J = 1, ... n)

where $\tilde{L}$ is a function dependent L:

$$\tilde{L}(I,J) = L(I,J) \circledast Z(m)$$

Z(m) is either F(m,T) or any function G(m)

$\circledast$ is an operator such as +,-,*,/, etc. See section III for further details.

When Z(m) and the operator $\circledast$ are not specified the differential equation reduces to the linear, constant coefficient case.

The differential equations are modified under certain special conditions as follows:

1) When an FF(H,T) equation is specified, it replaces F(H,T) in all differential equations, except for the dF(H,T)/dT equation which remains unaltered. This creates a 'FORCING function' for F(H,T), and permits its own regeneration.

2) A term $\tilde{L}(J,I)*F(I,T)$ is converted to $\tilde{L}(J,I)$ only when a 'Z' is entered in column 60 of the L(J,I) card. This generates a 'ZEROETH ORDER' term.

3) A 'K' entry in column 60 of an L(I,J) card is interpreted as

$$F(I,T) = \tilde{L}(I,J)*F(J,T)$$

$\tilde{L}(I,J)$ is thus considered an 'equilibrium constant' and the differential equations are treated accordingly.

4) When an F(I,T) is designated as a 'delay component' (by entry of DT(I) and DN(I)), all losses from I are equal to the inputs, but delayed an interval DT with a resolution DT/DN. In the differential equations the following change takes place:

$$\tilde{L}(J,I)*F(I,T) = \frac{\tilde{L}(J,I))}{\sum_{J\neq I} \tilde{L}(J,I)} \sum_{H} \tilde{L}(I,H)*F(H,T-DT)$$

Transient Solution:

Initial conditions: IC(J) is value of F(J,T) at the start of the solution.

NOTE: The instructions QO and QF entered in the category field of H DAT for a given time, T, are carried out only after all data requests at time T have been satisfied. The solution values derived at time T are used in the execution of the QO or QF instructions.

Steady State Solution:

In addition to and independent of the transient solution, steady state solutions M(J) and U(J) can also be calculated given a sufficient number of additional relations. In matrix notation the set of equations necessary for a steady state solution can be written as

$$\tilde{L}M = U \qquad (1)$$

$$AM+BU = C \qquad (2)$$

where M and U are vectors, $\tilde{L}$ is the matrix of elements [L(I,J)@Z(m)] defined as

$$\tilde{L} = \begin{vmatrix} -\tilde{L}(1,1) & \tilde{L}(1,2) & \tilde{L}(1,3) \\ \tilde{L}(2,1) & -\tilde{L}(2,2) & \cdots\cdots \\ \tilde{L}(3,1) & \cdots\cdots & \cdots\cdots \end{vmatrix}$$

where

$$\tilde{L}(I,I) = \sum_{\substack{J=0 \\ J\neq I}}^{N} \tilde{L}(J,I)$$

and A, B, C are defined by the set of dependence relations and steady state constraints.

F(I) or FF(I) in definitions of Z(m) are interpreted as M(I). UF(I) are not steady state inputs and are treated as G(I) if they appear in equations.

Oscillatory solutions for M(I) and U(I) are not provided for and will produce a diagnostic message indicating lack of convergence.

Steady State solution values appear as M(I) and steady state input vectors as U(I).

N equations (N = number of differential equations) of the form (2) above are required in order to obtain steady state solutions. By default, in SAAM, all U(I) are set equal to zero and all M(I) are assumed unknown. This provides N equations but it is a trivial set, and no solution results. At least one U(I) must be directly or indirectly specified as non-zero to obtain a non-trivial solution.

When an insufficient number of steady-state entries is given or when no steady state values are needed for any of the calculation requests under the heading H DAT, no solution of the set of steady state equations takes place. Even in the absence of a solution, however, any initial estimates entered for M(I) or U(I) are utilized by SAAM to satisfy other relations involving them.

A known value may be entered directly in fixed format under H STE or as a relation (or set of relations) under H STE or H LAM.

To specify an unknown value, an entry is made in fixed format under H STE by specifying an upper and lower limit with the entry. An initial estimate need be entered only if it is required for other relations.

For every U(I) specified as unknown, one of the default equations is automatically removed and, hence, another steady state relation, usually involving M(I) must be entered.

Note: The simultaneous set of dependence relation equations must be reducible to a set linear in parameters and/ unknown M(I) and/ or U(I). The initial estimates of the unknown M(I) and or U(I) will be used, if necessary, to complete the solution of parameter values from the reduced linear set. The steady state equations of constraint must reduce to a set linear in unknown M(I) and/or U(I). To introduce non-linearities into steady state constraints, a parameter may be set equal to some unknown M or U (as a dependence relation) and a function of that parameter can then be used as the coefficient of an unknown M or U in the steady state constraint.

For example, to impose the steady state constraint

```
M(1)*SIN(M(2)) + M(1)*M(2) = M(3)**2
```

enter as dependence relations:

```
P(13) = M(2)
P(27) = M(3)
```

and under the H STE heading enter the constraint:

$$(P(13) + SIN(P(13)))*M(1) = \begin{array}{c} P(27)**2 \\ \text{or} \\ P(27)*M(3) \end{array}$$

Requests for the calculation of steady state transports (or "flows", or "fluxes"), $\tilde{L}(I,J)*M(J)$, may be entered under H DAT (in the category field) as R(I,J):

$$R(I,J) = \tilde{L}(I,J)*M(J)$$

R(I,J) are not permitted as variables in equations.

M(I) and U(I) values are printed only if requested under H DAT (in the CATegory field).

A request for SA in the category field under H DATa automatically calculates the ratio of the transient solution F(I,T) to the steady state solution M(I) for the requested component I.

<u>Model Code 1</u> (See Model Codes 1, 2, 8, and 10 - Common features)

<u>Computational Procedure</u>:

A fourth order variable step size Runge-Kutta method is used to solve the set of differential equations of Model Code 1.

The steady state solution is obtained by the use of a modified Newton-Raphson method.

<u>Special Inputs</u>:

Card 2 - enter "1" in column 50. If this entry is blank the program chooses between model codes 1, 2 and 10, whichever is most appropriate based on the user's problem deck. (Model code 1 is not chosen for the constant coefficients case.)

Model Code 2 (See Model Codes 1, 2, 8, and 10 - Common features)

ANALYTIC SOLUTION

SPECIAL COMPARTMENTAL MODELS

This model code solves, analytically, differential equations with constant coefficients having the following special form:

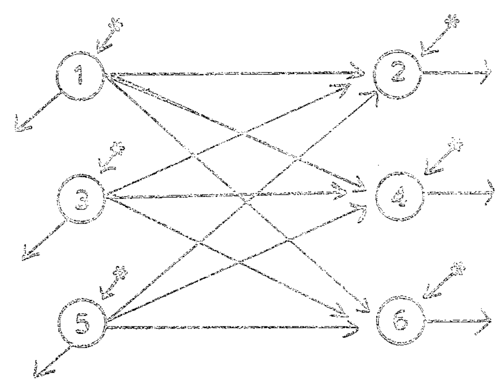
$$df_1/dt = -L_{11}f_1 \qquad df_2/dt = L_{21}f_1 + L_{23}f_3 + \dots - L_{22}f_2$$

$$df_3/dt = -L_{33}f_3 \qquad df_4/dt = L_{41}f_1 + L_{43}f_3 + \dots - L_{44}f_4$$

$$df_5/dt = -L_{55}f_5 \qquad df_6/dt = L_{61}f_1 + L_{63}f_3 + \dots - L_{66}f_6$$

$$\vdots \qquad\qquad\qquad \vdots$$

for a compartmental model this corresponds to the following general scheme:



The solution of these differential equations is in the form of sums of exponentials or sums of powers of T times exponentials. Model code 2 is further restricted to powers of T less than or equal to 2, (T^2).

Model Code 2 is the most efficient differential equations solution routine.

Special Input:

"2" in column 50 of card 2. If left blank, program will automatically choose this model code, when applicable.

Mode code 3

SIMILARITY TRANSFORMATION (MAPPING)

OPTION A

This model code is used for the mapping of compartmental models having time invariant rate constants (Berman & Schoenfeld, 1956). It can also be used, however, for straight similarity transformations on a matrix Y. The algorithm is

$$W = LYL^{-1}$$

where W is the transformed matrix.

The L(I,J) elements correspond to the SAAM L(I,J) variables. The matrix Y is entered under the heading H MAT. The elements W(I,J) are calculated and stored as F(K,T) in the following special (and peculiar) way: K = 1; T is a decimal number containing the information on I and J: 2 digits for I as the whole number and 2 digits for J after the decimal, (T=I.J). For example, W(3,2) appears as F(1,03.02), i.e., component 1 at T = 3.02. This mode of entry for W(I,J) permits simulation as well as data fitting.

In addition to the regular W(I,J) matrix entries, it is also possible to enter a W(0,J), which is defined as:

$$W(0,J) = \sum_{I=1}^{N} W(I,J)$$

In a compartmental model W(0,J) represents a loss path from compartment J to the outside. The values of W(I,J), $I \neq J$ and $I \neq 0$ correspond to the values of the rate constants. The value of W(0,J) is the negative of the value for the loss pathway and the value of W(J,J) is the negative of the sum of all rate constants from compartment J.

Special Inputs:

Card 2 - enter "3" in column 50.
- enter "1" in column 70.

H DAT

Only entries for which statistical weights are assigned need be entered. SAAM automatically calculates all W(I,J), including the W(0,J) terms.

By assigning statistical weights to certain W(I,J), convergence proceeds towards these values only. Hence, if a solution for a special model having certain W(I,J)=0 is desired, only these W(I,J) need be entered with zero observed values and with standard deviations.

H LAM

The values of L(I,J) as well as any equations that act as constraints on the L(I,J) are entered under this heading.

In a compartmental model the L(I,J) correspond to the eigenvector components (coefficients of solution exponentials). Hence, for example, initial conditions constraints are constraints on the L(I,J).

H MAT

The matrix Y is entered under this heading in accordance with the prescribed format.

OPTION B

All as under OPTION A except:
After similarity transformation is carried out, the signs of all W(I,J) - except W(J,J) and W(O,J) - are reversed.

To obtain OPTION B - DO NOT enter "1" in column 70 of card 2 in contrast with OPTION A.

Model Code 4

SOLUTION OF ALGEBRAIC FUNCTIONS

G(I), steady state and/or parameter dependence relations may be solved without invoking differential equations solutions.

Model Code 5

LINEAR COMBINATION OF SPECTRA

This model code is used to generate (and fit) a composite spectrum as a combination of known reference spectra. In using this algorithm, only data that have common abscissa (T) values are considered.

For each reference spectrum, J, SAAM calculates

$$F(J,T) = QO(J,T+L(J,1)) \qquad J = 2,3,\ldots$$

where QO(J,T+L(J,1)) is a (linear) interpolated value of the reference spectrum J. L(J,1) is a parameter that permits a T shift in the reference spectrum J as an extra degree of freedom in the fit.

The composite spectrum is generated through the relation

$$QC(I,T) = \sum_{\substack{J=2 \\ J\neq I}}^{N} S(I,J)*F(J,T) \qquad \begin{array}{l} J = 2,3,\ldots \\ I \neq 1 \\ I \neq J \end{array}$$

Only data that have common T values for all I and J are considered in the calculations.

Assigned values of I and J must be consecutive.

Computational procedure:
Linear regression of S(I,J) for given L(J,1).
Iterative adjustment of L(J,1)

Special Inputs:

Card 2: enter "5" in column 50.

H DAT: Derivatives of F(J,T) may be entered under THETA, if available. These entries are not necessary, but can be helpful.

May 1975
Rev Apr 1978

Model Code 8 (See Model Codes 1, 2, 8 and 10 - Common features)

ORDINARY NON-LINEAR DIFFERENTIAL EQUATIONS

COMPARTMENTAL MODEL

This is a non-linear version of Model Code 10. It is the default method when no model code is given for a problem involving non-linear differential equations. Occasional comparisons with Model Code 1 are recommended.

Model Code 10 (See Model Codes 1, 2, 8 and 10 - Common features)

LINEAR DIFFERENTIAL EQUATIONS WITH CONSTANT COEFFICIENTS

COMPARTMENTAL MODELS

This model code solves a set of differential equations having constant coefficients.

Mode of solution:

Special mode of solution is employed, using a combination of exponential extrapolation and convolution techniques. This method of solution is usually considerably faster than 4th order Runge-Kutta. It is recommended that solutions for linear systems derived from model code 10 be compared to model code 1 in unfamiliar situations or when doubtful results are obtained. It is the default method when no model code is entered for a problem and model code 2 does not apply.

Model Code 11

POPULATION MEAN AND COVARIANCE MATRIX

Purpose: Given a population of k studies in which each study i contains a set of n parameters with values X_i $(X_{i1}, X_{i2}, \ldots X_{in})$ and covariance matrix V_i, find the mean parameter values $\bar{X}$ $(\bar{X}_1, \bar{X}_2, \ldots \bar{X}_n)$ and the covariance matrix (V) for the population.

Solution equations: the program solves the following set of simultaneous equations, approximately

$$\bar{X} = [\sum_i (V_i + \bar{V})^{-1}]^{-1} [\sum_i (V_i + \bar{V})^{-1} X_i]$$

$$\bar{v}_{jm} = [1/(K-1)] \sum_i \sqrt{w_{ij} w_{im}} (X_{ij} - \bar{X}_j)(X_{im} - \bar{X}_m)$$

where

$\bar{v}_{jm}$ = (j,m) element of covariance matrix $\bar{V}$

w_{ij} = statistical weight of parameter j, study i, internally calculated.

Special Inputs:

Card 2 - NUMBER OF COMPONENTS = n = number of parameters

NUMBER OF ITERATIONS: Blank

MODEL CODE: "11"

H DAT (See footnote 1)

A complete set of adjustable parameters, 1 to n, must be entered for each study.

COMP: Parameter number (say j)

T: study number (see footnote 2) i (any number 1. to 999. Decimal required.)

OBSERVED VALUE: the value of X_{ij} - parameter j in study i

WEIGHT: enter "1" directly or through control card.

H LAM

Enter L(0,J) for J = 1, ..., n, where n is the number of adjustable parameters.

Additional Input:

Immediately after the standard deck the following are entered in the order indicated.

For each study (see footnote 1)

Heading card H MAT

Control card:

Col 1 – 10: The study number i (integer)

Col 11 – 20: Code (integer) for the type of matrix input which is to follow

"1" – covariance matrix

"2" – correlation coefficient matrix with standard deviations on diagonal.

"3" – normal equations matrix

"4" – normal equations matrix followed by vector of standard deviations

(Any one of the above may be used as input matrix)

Col 21 – 35: SIG for study i (E format).

(SIG = sum of squares of deviations divided by degrees of freedom.)

Matrix entries (footnote 3): See Section III for format.

Vector: Entered in matrix format (Section III)
This entry is required only if called for by code entered on "control card".

Footnotes:

(1) Punched cards for these entries can be obtained in proper format for each study i by entering "2" or "3" under <u>options</u> in either column 2 or 5 of card 4, when "running" study i under its model code. It is necessary to enter the problem ID on card 1 (Col 10 to 20) of the problem deck which is to generate the punched output. The problem ID must have the following special format, XXXIII.JJJJ, where: XXX are three alphabetic characters; III are three integers for the study number 'i'; JJJJ are one to four digits for other user identification purposes; the decimal point is always required.

(2) Study numbers must be non-zero and unique for each study involved. They are ordered internally by their integer values. The adjustable parameters are numbered internally, 1 to n for each study. The order of the adjustable parameters must be the same for ALL studies.

(3) Since the matrices are symmetric, only upper-right or lower left portions (including diagonal) need be entered.

Special Outputs:

INDIVIDUAL = I, CODE = J, SIG = X - identifies the problem, the type of matrix and SIG, respectively, for the matrix which follows.

MATRIX AS READ - is the matrix supplied to the program for an individual in the population being studied.

A-MATRIX (OPTIONAL) is the A-Matrix for an individual in the population.
Option: '1' in Column 6, Card 4.

Unlabeled special printout
Option: '1' in Column 6, Card 4.

CARD IMAGES -
Option: '1' in Column 11, Card 4.

Unlabeled special printout under final values
Option: '1' in Column 6, Card 4.)

WINDUP INFO.
WEIGHT(I), I=1, M STORED IN ROWS -
Weights as recalculated.
Option: '1' in Column 6, Card 4

VARIANCE-COVARIANCE MATRIX FOR POPULATION -
Punch Option: '1' in Column 5 of Card 4

PARAMETER	STANDARD DEVIATION FOR POPULATION	STANDARD ERROR OF MEAN

A table of values.

SIG FOR POPULATION = X - X is the variance of the parameters for the population being studied.

A-MATRIX FOR POPULATION
Punch option: '1' in Column 2, Card 4.

CORRELATION COEFFICIENT MATRIX FOR POPULATION

RES (I,J), I=INDIV., J=PAR.
Special printout
Option: enter '1' in Column 6, Card 4.

(RES - 2.*A*RES)/SIG FOR IND.
Special printout
Option: '1' in Column 6, Card 4.

CONAB FOR IND.
Special printout
Option: '1' in Column 6, Card 4.

PARAMETER	INDIV.	PROB. NO.	ORIG. VALUE	CALC. MEAN	ADJ. VALUE	MEAN OF ADJ. VALUE

The final table of values.

VARIANCE CO-VARIANCE MATRIX FOR ADJ. POPULATION - is the covariance matrix for the population calculated after the parameters (for each individual in the population) have been adjusted toward the mean within a 95% confidence limit.

S E C T I O N VII

COMPUTATIONAL PROCEDURES AND METHODS

The following are the computational stages in SAAM connected with the solution of a problem:

READ-IN

Prior to the solution of an individual problem, SAAM reads all problems in a run deck and encodes them into a series of records. The problems are then executed one at a time from these records as follows:

1) The records for a problem are read into core.

2) The information is reorganized as required by SAAM.

3) The correctness and consistency of the information is tested to the extent possible and a preliminary printout is given.

4) The problem is solved based on the initially specified parameter values. For adjustable secondary parameters values are calculated using multiple regression techniques. This constitutes a 'simulation' or 'zero-iteration' solution.

5) If the problem calls for iterations, the values of primary parameters are adjusted to achieve a least squares fit to the data.

6) Final results are calculated and printed.

7) Special calculations are carried out when called for.

8) Results are plotted.

READ-IN SEQUENCE

The problem identification card (card 1) is read and stored followed by cards 2 through 4. Cards 2 through 4 (default values) are added if they were not part of the problem deck. The time, date and program version are printed.

H DAT instructions are read and modified according to FORMAT cards, control cards and data generation cards.

H DAT TC(I) instructions are read in ascending order of I.

Statistical weights are assigned to each instruction as called for by the input.

H KAP, H LAM, H SIG, H PAR, H DEP, H INI, and H STE entries are read next in that order. Each entry of a standard deviation on a parameter card generates a weighted datum to be used in the overall least squares fitting process.

H STA constraints are read and stored as equations. They are used jointly with the H DAT entries to achieve adjustment of the parameters and a least squares fit to the observations. A weighted datum is generated for each statistical constraint entered under this heading.

H PCC TC(I), H SCC TC(I), and H ICC TC(I) entries are read, coded and saved on an I/O device to be used subsequently for calculations of T-interrupt changes.

All equations that appear in the input are stored for use in subsequent calculations.

SPECIAL INPUTS AND SET-UP

H MATrix, H SS3 entries are read only if called for by the model code or the options entered.

After all records of a problem have been read, some instructions may be added or deleted by SAAM to satisfy the requirements of a particular model code. Instructions under H DAT are then ordered in ascending order of T within each of the data blocks separated by T-interrupts.

TESTING AND PRELIMINARY PRINT-OUT

During and after the read-in, the input is tested for consistency and errors. Diagnostics are printed as needed.

Reorganized information is printed when called for (card 4) and some standard printout is always provided.

The card images of the problem deck are printed if requested (card 4).

When fatal errors are detected the problem is terminated.

STATISTICAL WEIGHTS ASSIGNMENTS

Each entered datum is assigned a statistical weight, W(K), which is proportional to the square of the reciprocal of the estimated standard deviation (SD) for that datum:

$$W(K) \sim [1/SD(K)]^2$$

The weights are then normalized so that their sum for all data equals the number (N) of weighted data points entered:

$$\sum_K W(K) = N$$

Data for which no SD are directly or indirectly entered are assigned zero weights.

If no standard deviation is given for any of the data, a weight of 1 is assigned to all.

Standard deviations for data are available to SAAM through direct entries, or indirectly through control cards entries such as FSD=X (fractional standard deviations), or RQO=X.

Although direct assignment of weights to data are possible through a WT=X entry on a control card, such an assignment is considered by SAAM as 'relative' and cannot be used for error estimation. Its use is not recommended, except for WT=0 which assigns zero weights to data which one may wish to exclude statistically in the data fitting process.

When estimated SD's are given with data, SAAM calculates a variance for the data. This is printed as SIG READ-IN:

$$\text{SIG READ-IN} = N/\sum_k \frac{1}{SD_k^2}$$

Initial weights W(C) are assigned to statistical constraints having a standard deviation SD(C) as follows:

$$W(C) = \frac{\text{SIG READ-IN}}{[SD(C)]^2}$$

INITIAL SOLUTION (SIMULATION)

The initial solution (iteration zero) is a simulation based on the initial estimates of primary parameters, initial conditions, dependence equations, given functions and other instructions. F(I,T) and G(J) values are calculated and used to determine a value for each datum entered. F(I,T) values for components having adjustable secondary parameters are initially calculated using initial estimates of the secondary parameters. Using data that are linear in the adjustable secondary parameters only, new estimates for these parameters are derived using linear regression. All F(I,T) and other functions requiring these parameters are then recalculated to reflect the final values of the secondary parameters.

An estimate of the variance of the data, SIG(CALC), based on the difference between their observed (QO(K)) and calculated (QC(K)) values are obtained:

$$\mathrm{SIG(CALC)} = \sum_{N} \frac{(\mathrm{QO}(K)-\mathrm{QC}(K))^2 W(K)}{N-P}$$

where P is the number of primary adjustable parameters, and N is the number of weighted data.

ITERATIONS

When a problem calls for iterations (card 2), several things are checked after the initial solution before proceeding.

1. It is determined whether or not there are indeed adjustable primary parameters.

2. If no statistical uncertainties are entered with the data, SAAM arbitrarily assigns unit weight to each, executes the initial solution and then terminates.

3. If SIG(CALC) after the initial solution is greater than SIG(READ-IN) by a factor of 100 or more no iterative adjustments are permitted since it is assumed that initial estimates of parameters are probably too poor to permit convergence. This termination can be overcome by improved initial estimates or by increasing constant used to define the standard deviations for all entered data. This will not alter the final least squares parameter values or their estimated uncertainties if the SIG(CALC) after iteration is less than SIG(READ-IN). The latter change should only be made if convergence with poor initial estimates is likely and efficient.

A. Calculation of partial derivatives

To calculate corrections for initial estimates of primary adjustable parameters, partial derivatives of the calculated values QC(K) with respect to the adjustable parameters are derived by numerical approximation:

$$\frac{\partial QC(K)}{\partial\lambda(I)} \approx \frac{\Delta QC(K)}{\Delta\lambda(I)} = \frac{QC'(K)-QC(K)}{\lambda'(I)-\lambda(I)} = \frac{QC'(K)-QC(K)}{P_1\lambda_i}$$

for K=1...N and i=1...P

where: $\lambda'(I) = \lambda(I) + \Delta\lambda(I)$

$\Delta\lambda(I) = P_1 * \lambda(I)$ (P_1 is entered on card 3 and has a default value of .01.)

and QC$'$(K) are the solution values based on $\lambda'(I)$.

The partial derivatives are entered in an NxP matrix, a.

B. Calculation of the vector of parameter changes

Let the Nx1 matrix b be defined by b(K) = QC(K)-QO(K), and a NxN diagonal matrix W by W(K,K) = the assigned weight for datum K. A set of Normal Equations AX=C can be generated where $A = a^T Wa$ and $C = a^T Wb$, X is the vector of corrections. In the printout X is referred to as RES, the matrix a as LITTLE A, and the matrix A is the A-MATRIX. The correction vector, X, is calculated from the matrix relation: $X = A^{-1}C$.

C. Parameter Adjustment

After the correction vector is calculated the individual RES(I) are further modified one at a time, by a factor

$$\frac{1}{\dfrac{VAR(I)}{[P*RES(I)]^2} + 1}$$

where P is a constant (card 3) and VAR(I) is the calculated estimate of the variance for the I^{th} adjustable parameter. (When not entered, P is assigned a default value of 3 by SAAM.) The effect of this correction is that when a variance is very large compared to the calculated $(RES)^2$, the factor is very small and the correction tends to zero. However, when the variance is small compared to $(RES)^2$, the factor tends to unity. Modification of the RES(I) starts with the last adjustable one. After it is adjusted the remaining unmodified RES(I) are recalculated conditional on the acceptance values for the modified ones. New estimates of variances for the unmodified RES(I), conditional on the accepted RES(I), are also recalculated and used for subsequent adjustments.

After the RES vector is fully modified, it is added to the vector of adjustable parameter values, λ, and the resultant values are tested against the imposed upper and lower limits. If limits are violated the total correction vector RES is scaled down to stay within the most restricting limit. The scaling factor is called CONAB.

A new solution, $QC_p(K)$ is obtained for the adjusted parameter values. This, together with QC(K) of the previous solution and the observed values QO(K) are then used to scale the RES correction vector further to obtain an improved fit of the data. A scaling constant CON is calculated based on a linear extrapolation:

$$CON = \frac{1}{N} \sum_{K=1}^{N} \frac{QO(K)-QC(K)}{QC_p(K)-QC(K)}$$

Because of non-linearities, this adjustment is repeated until the ratio of the new sum of squares to the previous one is equal to or greater than CONMIN - or after three tries in any one iteration, whichever occurs first. The value of CONMIN is read in on card 3.

If the sum of squares becomes worse, the RES vector is cut down by a factor of ten, and the procedure is repeated.

The best sum of squares obtained during the various adjustment stages is recovered as the final solution of an iteration.

The error matrix for the adjustable parameters is obtained by multiplying the inverse Normal Equation matrix, A^{-1}, by the best estimate for the variance of the data, SIG(CALC) or SIG(READ-IN), whichever is the smaller.

Iterations are usually carried out in pairs ('odd' and 'even'). In the 'odd' iterations partial derivatives are calculated as discussed above and the set of normal equations $(a^TWa)X = a^TWb$ is solved to obtain the initial correction vector X. In the subsequent 'even' iteration partial derivatives of the preceding iteration are used with a new <u>b</u> matrix determined from the solution of the preceding iteration. Thus, the 'even' iterations are further refinements of the 'odd' iterations.

D. <u>Termination of iteration</u>

Termination results when the maximum number of iterations (card 2) has been reached or the fractional change in the total sum of squares over a pair of iterations ('odd' and 'even') is less than (1.-E) (card 3).

S E C T I O N VIII

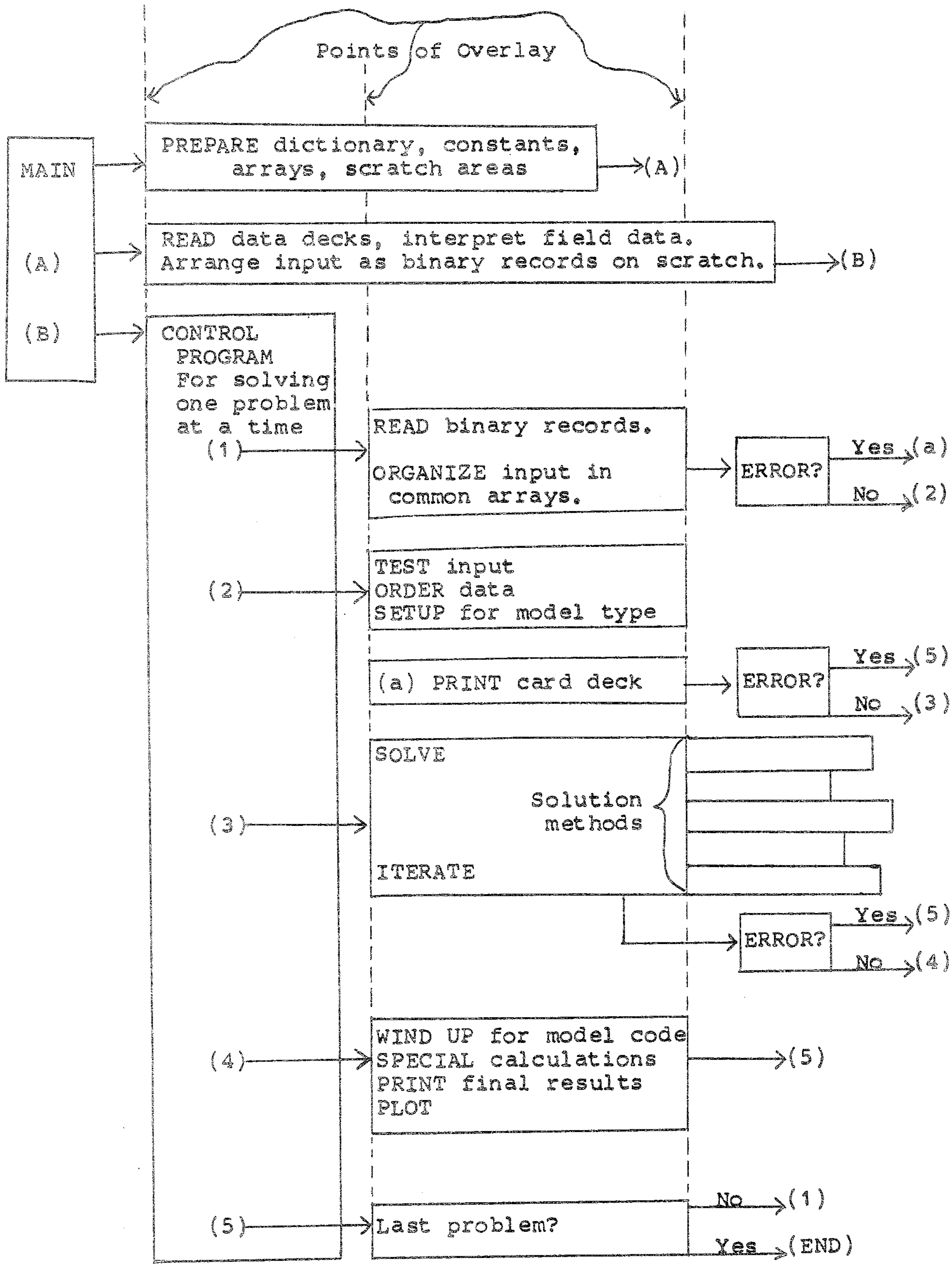
PROGRAM ORGANIZATION

SAAM is a large system (approximately 30,000 Fortran statements). Its size necessitates the overlaying, in core, of the program segments involved in read-in, computation, and final output. Moving SAAM from one computer system to another is complicated by differences in core limits, permissible overlay structure, language limitations and the availability of system library routines.

A serious attempt has been made to use a compatible FORTRAN IV and to make SAAM independent of word size and machine dependent languages. Those differences which must be taken into account have been isolated in several sub-programs which are specific for each computer system.

Problems that have arisen in conversion involve logical unit assignments and typeless functions. The letters 'CHNGE' in col. 1-5 now appears in each FORTRAN program (of Version 27) which contains a typeless function or an IO problem. Deleting 'CHNGE' from col. 1-5 leaves an INTEGER statement. The statement 'INCLUDE XXX' requires that a group of statements in an element called XXX replace the INCLUDE statement.

The flow of the program, indicating the logical arrangement for overlay, can be described schematically as follows:


Points of Overlay
MAIN
(A)
(B)
PREPARE dictionary, constants, arrays, scratch areas
(A)
READ data decks, interpret field data. Arrange input as binary records on scratch.
(B)
CONTROL PROGRAM For solving one problem at a time
(1)
READ binary records.
ORGANIZE input in common arrays.
ERROR?
Yes (a)
No (2)
(2)
TEST input
ORDER data
SETUP for model type
(a) PRINT card deck
ERROR?
Yes (5)
No (3)
(3)
SOLVE
Solution methods
ITERATE
ERROR?
Yes (5)
No (4)
(4)
WIND UP for model code
SPECIAL calculations
PRINT final results
PLOT
(5)
(5)
Last problem?
No (1)
Yes (END)

Subroutines in SAAM27

	1	READ1	2	READ2	3	PASSES	4
SKPRTL	5	CONTRL	6	READ6	7	SZCALC	8
SUMMEQ	9	FINDIF	10	SETV	11	KOUNTJ	12
PRINT1	13	PRINT2	14	NEWDEK	15	TRACK	16
DECIDE	17	ORDER	18	TEST	19	PAREQU	20
VJJDEL	21	DEQSOL	22	SCCALC	23	MATINV	24
SSDET	25	WTSUB	26	SETUP	27	WTDSS	28
SUB1	29	PRTIAL	30	AMX	31	READ7	32
DEVAMX	33	RESDET	34	ADDRES	35	INTMTB	36
CONDET	37	TRMNAT	38	SOLV9	39	QCSUM	40
CORCO	41	SIZTST	42	MP1	43	MATDIV	44
SOLV7	45	SOLV1	46	SETUP7	47	SOLV6	48
HALF7	49	SIZCAL	50	EQTDEP	51	REWIND	52
HALF1	53	HALF2	54	SPCL	55	SOLV2	56
SOLV3	57	SLITE	58	SPCL1	59	SPCL3	60
SETFM	61	SOLV5	62	IPLOT	63	PRTSLV	64
SLVIER	65	CALEQU	66	HALF3	67	SETUP5	68
SPCL2	69	INMOD	70	TSTEQU	71	CLKRD	72
PRINT5	73	PRINT6	74	SUMLST	75	STRVEC	76
TAUBAR	77	YINV	78	SHFTER	79	PRINT9	80
HALF5	81	HALF6	82	PRINT7	83	PLOT1	84
FILL	85	NXFILL	86	ADJKS	87	CMPPAR	88
MP101	89	ADDLST	90	TMORDR	91	SETSHF	92
IICHBT	93	PRINT8	94	PARTC	95	WINDUP	96
SETP3	97	SETP11	98	SOLV11	99	WNDP11	100
SETCLR	101	INITL	102	READMX	103	SOLV10	104
PARIN	105	OPLIST	106	WNDP12	107	DIGEQU	108
SIMSLV	109	DBLFLD	110*	MAIN	111	OUTMOD	112
ADDSHF	113	RSTRSH	114	GLMRHO	115	PACK	116
UNPACK	117	CALIST	118	SUMUP	119	DQKALC	120
TESTMU	121	SKLIN	122	PRIME	123	MATMLA	124
PARFND	125	MSOLV	126	GROUP	127	SOLVE	128
NDTBTS	129	FLSEND	130	FLSFWD	131	FLSBKD	132
NEQSOL	133	NEQS	134	ADDMAT	135	PUNCH1	136
HALF8	137	INFO	138	PUNCH	139	DFLADJ	140
SHFTC	141	QCCALC	142	NEXT	143	TCBEGP	144
SAVTC	145	ZROBIT	146	LINTST	147	RNORM	148
GETBIT	149	INDSET	150	ADJSKG	151	EQUIL	152
QCVSQO	153	INSEGG	154	LAMSH	155	SETSYS	156*
DATMOD	157	JACOBI	158	DIFEQU	159	EQURAT	160
INTGRT	161	SLVTNF	162	STINPT	163	MATMLS	164
OCTAL	165	NDTEMP	166	CRD234	167	EQILST	168
SRCHTB	169	INAME	170	ADDNAM	171	BLDBUF	172
BILDMX	173	POSTAP	174	NAMFLD	175	IMDATE	176*
IMTIME	177*	BLDMX	178	WCALC	179	DQPREP	180
DERIV2	181	SHFCMP	182	XDLDT	183		184
DCODIT	185*	NCODIT	186	SETBIT	187	JPLOT	188
HEAD	245	EQN	246	ARRANG	247	DICT	248
WIND1	249	LIST	250	CONVRT	251	XPAND	252
SHIFT	253	NCODE1	254	NCODE2	255	NCODE3	256
FORMAT	257	NCODE4	258	WIND2	259	WIND	260
SEARCH	261	WIND3	262	WIND4	263	WIND5	264
LIST1	265	COREQN	266	PRINTA	267	CTAPE	268
EXPAND	269	DELETE	270	ERROR	271	WIND2A	272
WIND4A	273		274	XPAND1	275	COPY	276
ERRPRT	277		278		279		280
MP40	281						

*These programs differ entirely or in part on different systems.

FILE ASSIGNMENTS IN SAAM

The user has the option to request special outputs during the execution of a problem. Some of these are saved in specially designated files by SAAM. To retrieve these, the user must know the logical unit numbers assigned to these files. The following table gives the equivalences between internal SAAM names and the unit numbers for various computers. The files available to users for optional outputs are indicated in the table:

NAME*	LOGICAL UNIT UNIVAC	LOGICAL UNIT IBM
NTAPE0 (input)	5	5
NTAPE1 (print)	6	6
NTAPE2 (punch)	1	7
NTAPE3	10	10
NTAPE4 (options)	11	11
NTAPE5	12	12
NTAPE6 (options)	13	13
NTAPE7	0	14
NTAPE8 (options)	9	15
NTAPE9	8	8
ISSINF	15	17
JSSINF	14	19
NUNIT (options)	22	22

* All file names except NUNIT are in blank common and are defined in SUBROUTINE SETSYS. NUNIT is a local name defined in SUBROUTINE PRTSLV.

S E C T I O N IX

COMMENTS AND SUGGESTIONS

COMPUTING TIME

Problem Solution time refers to the total time necessary to run a problem.

Equations Solution time refers to the time required for a single solution of the model equations to yield values for all T values specified under the various H DAT headings.

The number of equation solutions (E) necessary to solve a problem cannot be predicted precisely but will lie in the range given by:

$$(1+A)I + 1 \leq E < (6+A)I + 2$$

where A is the number of primary adjustable parameters and I is the number of iterations in the solution. For zero iterations (simulation) E = 1.

The total time for the solution of a problem equals the time for a single equation solution times the number of equation solutions involved, plus some overhead for preparing the problem and printing the results.

The time for a single equation solution depends on the model employed.

a) Analytic solution models. The time for these solutions is usually short but depends on the complexity of the equations and on the number of data points.

b) Numerical solutions. This applies mainly to the solution of differential equations using the Runga-Kutta method. The time for a single equations solution is approximately proportional to the product

LM x TM x L

where: LM = maximum value of L(J,J)

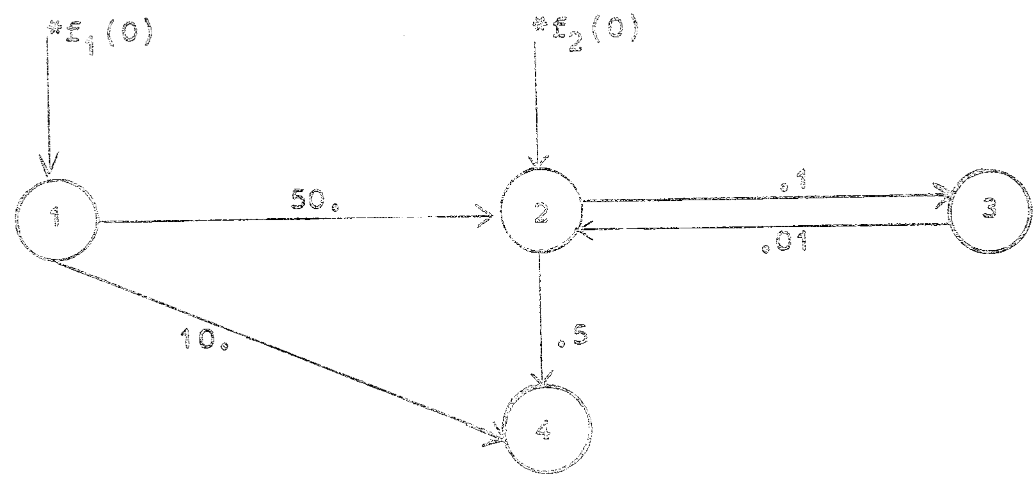
TM = largest T value for data

L = number of L(I,J) parameters in the problem.

The actual time depends on the computer speed and efficiency and on the complexity of the problem and it is difficult to give a simple formula for this.

The solution times for differential equations using the model code 10 method is usually considerably faster than Runga-Kutta. Precision may at times, however, be sacrificed. Occasional cross-checking between model codes 10 and 1 is therefore advisable.

T-interrupts may sometimes be employed to reduce computing time in the numerical solution of differential equations. It requires the reduction in the values of the largest L(J,J) in the model, and can only be done if after such a change the solution remains effectively unaltered. Consider the following schematic of differential equations as an example:



The equation solution time for this model is governed by the largest L(J,J) which is L(1,1) = 50. + 10. = 60. However, it is obvious that compartment 1 is essentially depleted after .1 units of time. Thus, a T-interrupt change at T = .1, setting L(2,1) = L(4,1) = 0 would hardly alter the solution and establish a new L(J,J) maximum, namely, L(2,2) = .1 + .5 = .6. From this time on the solution could proceed about 100 times faster.

CONVERGENCE, UNIQUENESS AND CONSISTENCY

To judge whether a solution has converged and, if so, whether it is consistent and unique, the following measures and hints are useful.

a) Sums of squares (SS) for each "compartment" and total SS (including statistical information) are printed at the end of each iteration. It is necessary for convergence that the improvement in SS for the last iteration be small (a few percent or less compared to previous iteration). This in itself, however, is not sufficient to guarantee convergence.

b) In each iteration a set of corrections is calculated for the independently adjustable parameters. These corrections are then multiplied by a factor, CONAB, to optimize the fit of the data. CONAB values close to unity at the end of an iteration suggest "good" convergence. CONAB values much less than unity suggest that the model may be ill-conditioned, or non-unique and that convergence to a least squares fit is sluggish. CONAB values are printed with each iteration.

c) The magnitudes of the corrections calculated in the beginning of an iteration become small compared to the corresponding values of the parameter in the neighborhood of a least squares fit.

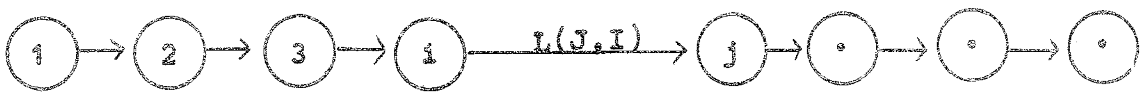
d) Estimated Standard Deviations are printed out with the final results. These are determined at the beginning of the last iteration. They approximate the "true" estimated standard deviations only if the problem is near a least squares solution at the beginning of the last iteration. Standard deviations which are large compared to parameter values could mean non-uniqueness of the solution and slow convergence.

e) If the actual fit as inspected by eye seems "good", in that the scatter seems random, and if the Sum of Squares (SS) is comparable to an independently derived "reference" SS, the solution obtained is near a least squares solution; it may, however, still be non-unique.

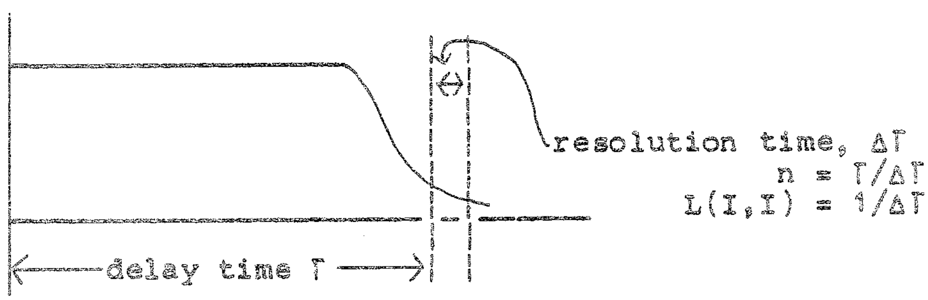
f) If the fit contains systematic deviations but otherwise satisfies all other least squares criteria the solution is inconsistent. The estimated standard deviations for such a solution may be meaningless.

DELAYS

Frequently it is desired to introduce a delay within a kinetic process. For example, iron incorporated in a red cell is not released until the cell "dies". Red cells have a life span of about 100 ± 10 days. Thus, a 100 day delay is required in the solution with a resolution of about 10%. There are several ways to introduce a 'delay'. One is through the use of a series of compartments as follows:



If a delay time τ is desired, **n** compartments may be set up in series, each with an average turn-over time τ/n (L(J,I). = n/τ). All the L(J,I) may be set equal to each other. The larger the number of compartments **n**, the closer the series of compartments approaches a true time delay. The resolution time Δτ of this delay is to a first approximation equal to the turn-over time of a compartment (1/L(I,I)):



Another way to accomplish a delay is by the use of a delay element. For the example cited, a delay element, I, would be created by setting

DT(I) = 100. and DN(I) = 10.

SIMULATION

One can obtain solutions for a model in the absence of any real data by entering "dummy" data. Such "data" need have entries only under COMPONENT and T - leaving everything else on the "data" card blank. The calculated values will correspond to the entered "data".

ADJUSTABLE INITIAL CONDITIONS

There are no provisions now in the program for dealing with adjustable initial conditions directly. Indirectly, however, this can be accomplished by setting the initial conditions equal to some specially assigned adjustable parameter (e.g. IC(5) = P(17), and P(17) is adjustable).

PARALLEL PATHWAYS

Sometimes one desires to introduce 2 or more parallel pathways between 2 compartments, (for example, the simultaneous presence of passive diffusion and active transport). The program does not permit duplicate parameter designations. This can be accomplished, however, indirectly by setting the L(I,J) between the compartments equal to the sums of two other parameters or making them function-dependent. For example,

L(1,2) = P(12) + P(13) or

L'(1,2) = L(1,2)+G(15)

where G(15) = P(10)*P(11)/(P(10)+P(2)).

S E C T I O N X

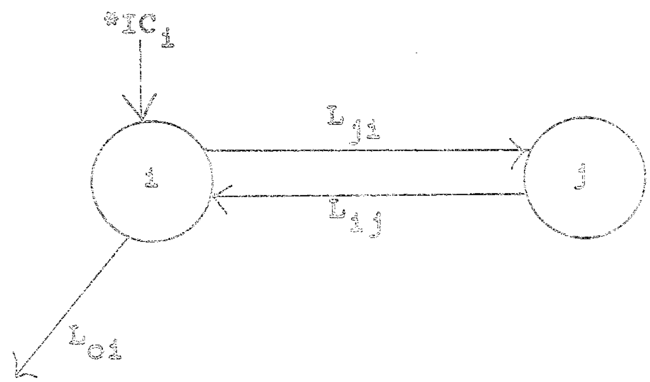
EXAMPLES

The following are examples of various problems run on SAAM. A statement of the problem, mathematical description, a schematic and a listing of the data deck required for each example is generally given. The dashed and numbered lines appearing on top and bottom of some data deck listing are given only for purposes of numbering of columns, and are not part of the running deck.

The first card of each data deck may contain a problem identification which consists of three initials followed by a number (e.g., MAN002.01). As will be seen by the reader - several model codes can sometimes be used to solve the same problem.

COMPARTMENTAL MODEL REPRESENTATION:

Schematic:



The circles define compartments i and j. The L_{ij} are fraction of material in j transported to i per unit time. L_{oi} is fraction of material in compartment i leaving it irreversibly. IC_i is the initial condition in compartment i.

Differential Equations:

The schematic implies the following set of differential equations:

$$df_i/dt = -L_{ji}f_i - L_{oi}f_i + L_{ij}f_j \qquad f_i(0) = IC_i$$

$$df_j/dt = L_{ji}f_i - L_{ij}f_j$$

SAAM Notation:

The above equations are implied in SAAM through entries of the following parameters under one of the parameter headings:

```
H LAM
   L(0,I)
   L(J,I)
   L(I,J)
   IC(I)
```

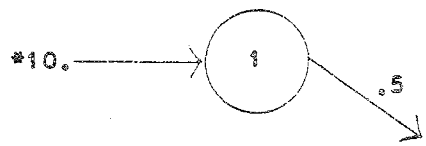
Solution requests for f_i, f_j or functions of them for specified values of T are entered under an E DAT heading.

__Simulation__ - is the solution of a specified model for a given set of parameter values and initial conditions.

Instructions as to the functions and the T values for which solutions are desired are entered in SAAM under the heading H DAT. Frequently the component number and the T value are the only entries needed. There are, however, additional requests that can be entered in the CATEGORY field. These include the dictionary names in SAAM as well as special functions.

<u>Simulate</u>: One Compartment Model

<u>Schematic</u>:



<u>Differential Equations</u>:

$$df_1/dt = -.5f_1 \qquad f_1(0) = 10.$$

solve for t = 0, .2, .4, .6, 1., 2., 3, 4, 8 units of time.

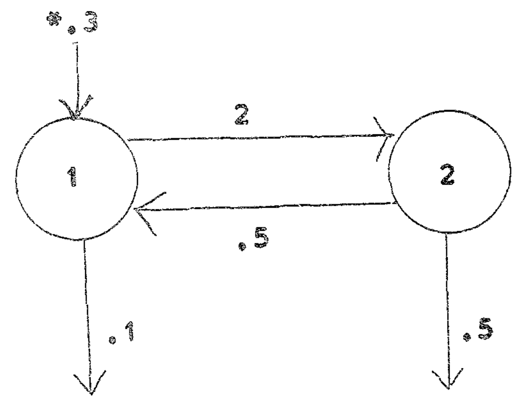
<u>SAAM</u>
<u>Method of Solution</u>: Analytic - using model type 2.

<u>Problem Deck</u>:

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
--------------------------------------------------------------------------------

A SAAM27 MAN                 SIMULATION - ONE COMPARTMENT MODEL
C MODEL TYPE 2 WILL AUTOMATICALLY BE SELECTED BY SAAM IN THIS CASE SINCE NO
C OTHER MODEL TYPE IS SPECIFIED.
H PAR
   L(0,1)   .5
H INI
   IC(1)    10.
H DATA
C C IN COLUMN 1 OF CARD SPECIFIES COMMENT CARD AND IS IGNORED BY SAAM.
C COLUMNS 2 AND 3 CONTAIN COMPONENT NUMBER, IN THIS CASE COMPARTMENT 1.
C ANY NUMBER UP TO 25 COULD HAVE BEEN USED.
C ENTRY IN COLUMNS 13 - 25 SPECIFY TIMES FOR WHICH SOLUTION VALUES ARE
C DESIRED.
  1         0
  1         .2
  1         .4
  1         .6
  1         1.
  1         2.
  1         3
  1         4
  1         8
--------------------------------------------------------------------------------
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

Simulate: Two Compartment Model

Schematic:



Differential Equations:

$$df_1/dt = -2.1f_1 + .5f_2 \qquad f_1(0) = .3$$

$$df_2/dt = 2f_1 - 1f_2 \qquad f_2(0) = 0$$

SAAM
Method of Solution: Differential equations, model type 10.

Problem Deck:

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

A SAAM27 MAN                          SIMULATION - TWO COMPARTMENT MODEL
H LAM
   L(0,1)    .1
   L(2,1)    2
   L(1,2)    .5
   L(0,2)    .5
H INI
   IC(1)     .3
H DAT
  1          .1
  1          .2
  1          .5
  1          1.2
  2          .1
  2          .2
  2          1.2
  2          .5
C T ENTRIES NEED NOT BE IN ASCENDING ORDER.  WHEN THEY ARE NOT - SAAM
C REARRANGES THEM FOR PURPOSES OF COMPUTATION.

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

Simulate: Sum of Two Exponentials

$$q = .2e^{-.5t} + .3e^{-.05t}$$

for t: 0, 2, 4, 10, 15, 20, 50, 100

SAAM
Method of Solution: G-function

G(3) = .2*EXP(-.5*T) + .3*EXP(-.05*T)

Problem Deck:

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

A SAAM27 MAN                     SIMULATION OF SUM OF TWO EXPONENTIALS
H DAT
X  G(3)=.2*EXP(-.5*T) + .3*EXP(-.05*T)
C SELECTION OF 3 IN G(3) IS ARBITRARY.  IT COULD HAVE BEEN ANY NUMBER.
C WITHIN PERMITTED RANGE.
101G(3)
C 101 IS A CONTROL CARD ASSIGNING THE COMPONENT NUMBER 1 AND THE FUNCTION G(3)
C TO THE DATA ENTRIES THAT FOLLOW.
          0
          2
          4
         10
         15
         20
         50
        100

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

Simulate: Sine Function

$$q = 1.2 \sin(3t+.5)$$

for t = .1, .2 ... 2.

SAAM
Method of Solution: G-function

G(1) = 1.2*SIN(3*T+.5)

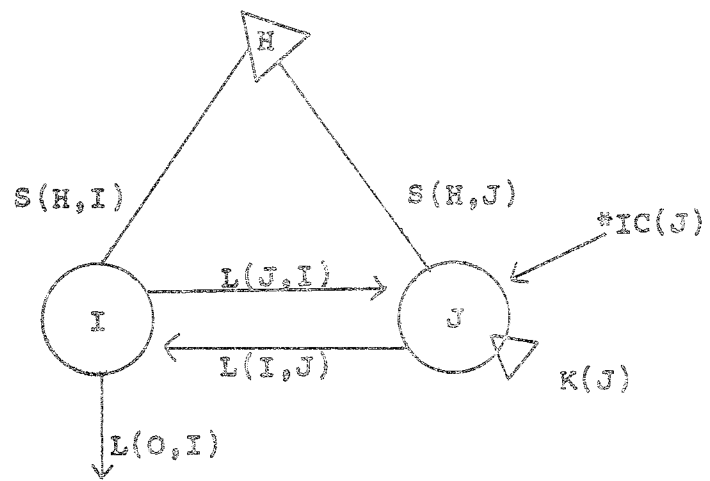
Index of G(1) is arbitrary.

Problem Deck:

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

A SAAM27 MAN                  SIMULATE SINE FUNCTION
4  4       1
H DATA
101G(1)
            .1
2           .1                          19.
C ABOVE IS DATA GENERATION CARDS, REQUESTING 19 DATA IN INCREMENTS
C OF .1 UNITS OF T.
X G(1) = 1.2*SIN(3*T+.5)

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

S(I,J) AND K(I) PARAMETERS

Schematic:



Differential Equations:

$$df_i/dt = -L_{ji}f_i - L_{oi}f_i + L_{ij}f_j$$

$$df_j/dt = L_{ji}f_i - L_{ij}f_j \qquad f_j(0) = IC_j$$

$$q_j = K_j * f_j$$

$$q_h = S_{hi}f_i + S_{hj}f_j$$

SAAM

Component H is called a SUMMER. Component J is a "regular" compartment.

In SAAM notation the model and SUMMER are implied through the parameters entries,

L(I,J)
L(J,I)
L(O,I)
S(H,I)
S(H,J)
K(J)

Simulate:

$$q = e^{-3t} - .00095e^{-.1t} + .00095e^{-.0067t}$$

for t = .5, 1, 1.5, 3, 6, 8, 10, 12, 14, 16, 18, 20, 30, 40.

SAAM

Method of Solution: G-function

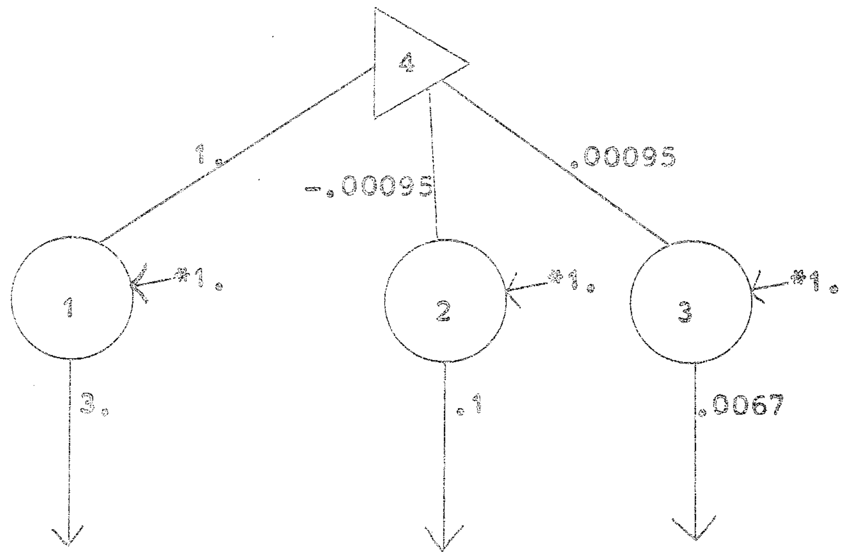
G(1) = EXP(-3*T) - .00095*EXP(-.1*T) + .00095*EXP(-.0067*T)

Problem Deck:

```
          1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

A SAAM27 MAN                      SUM OF 3 EXPONENTIALS
C G-FUNCTION SOLUTION METHOD
H DAT
XG(1)=EXP(-3*T)-.00095*EXP(-.1*T)+.00095*EXP(-.0067*T)
101G(1)
            .5
            1.
            1.5
            3.
2           2.                            7.
2           10.                           2.
C ABOVE ARE TWO DATA GENERATION CARDS.  THE SECOND ONE TAKES OFF FROM
C WHERE THE FIRST ONE ENDS.

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
12345678901234567890123456789012345678901234567890123456789012345678901234567890
          1         2         3         4         5         6         7         8
```

Alternate Method: Compartmental Model

Schematic:



SAAM
Method of Solution: Model type 2.

Problem Deck:

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


A SAAM27 MAN                     SUM OF EXPONENTIALS
C COMPARTMENTAL MODEL SOLUTION METHOD
H DATA
104
            .5
            1.
            1.5
            3.
            6.
2           2.                             7.
2           10.                            2.
H PAR
   L(0,1)   3.
   L(0,2)   .1
   L(0,3)   .0067
   S(4,1)   1.
   S(4,2)   -.00095
   S(4,3)=-S(4,2)
H INI
   IC(1)    1.
   IC(2)    1.
   IC(3)    1.

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

DATA FITTING

To fit data, some additions need to be made to the simulation entries denoted earlier.

1. Under H DAT, in addition to component number and time, an observed value (cols 27 to 40) must be added for at least some data. For each observed datum a measure of uncertainty (standard deviation or fractional standard deviation) must also be specified (cols 42 to 55) either directly or through a control card.

2. For the parameters that are to be adjusted, a range of adjustment must be specified through lower and upper limits. These are entered in cols 27 to 40 and 42 to 55, respectively.

3. Adjustable L(I,J) parameters require initial estimates. Adjustable linear parameters S(I,J) and K(I) usually do not require initial estimates.

Fit: Straight line

$q = K_1 + K_2 t$, given data having standard deviation of .05.

SAAM
Method of Solution: G-function

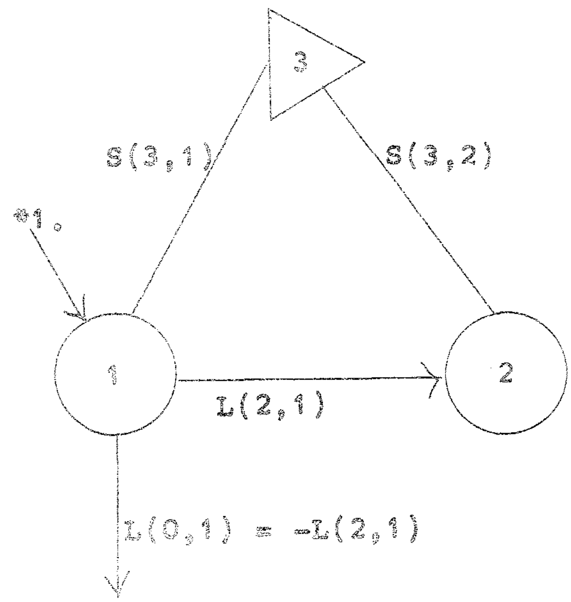
G(1) = K(30) + K(31)*T

Problem Deck:

```
              1               2               3               4               5               6               7               8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - 

A SAAM27 MAN                FIT TO STRAIGHT LINE (USING G-FUNCTION)
H DATA
XG(1)=K(30)+K(31)*T
101G(1)                                 SD=.05
         1.5            .60
         2.             .72
         3              .78
         3.5            .84
         5              1.02
         6.             1.11
H PAR
 K(30)                  -100            100
 K(31)                  -100            100

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - 
12345678901234567890123456789012345678901234567890123456789012345678901234567890
              1               2               3               4               5               6               7               8
```

Alternate Method of Solution: Compartmental model

Schematic:



In this arrangement the solutions F(1,T) = 1 and F(2,T) = T are arrived at through the differential equations denoting the compartmental model.

QC(3) = S(3,1)*F(1) + S(3,2)*F(2)

SAAM
Problem Deck:

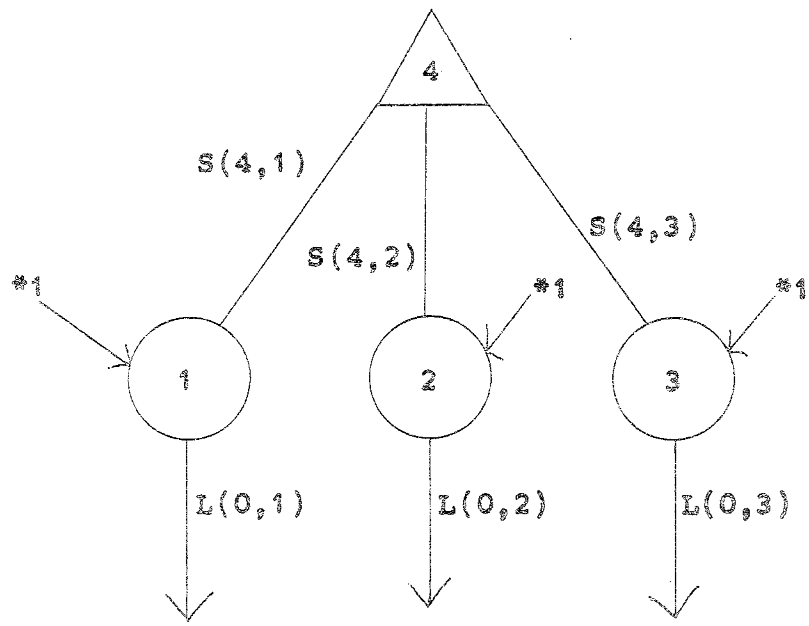
```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - 


A SAAM27 MAN002.01            FIT OF DATA TO STRAIGHT LINE (COMP METHOD)
H DATA
103                                          SD=.05
            1.5           .60
            2.            .72
            3             .78
            3.5           .84
            5             1.02
            6.            1.11
H LAM
   L(2,1)=1.
   L(0,1)=-L(2,1)
C L(0,1) WAS INTRODUCED TO KEEP F(1) CONSTANT.
  S(3,1)                  -100.          100.
 S(3,2)                   -100.          100
C NOTE S(I,J) ENTRIES ARE PERMITTED UNDER THE H LAM HEADING.
H INI
 IC(1)       1.

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - 
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

Fit: Sum of 3 exponentials

$$q = S_1 e^{-L_1 t} + S_2 e^{-L_2 t} + S_3 e^{-L_3 t}$$

SAAM
Method of Solution: Compartmental Model

Schematic:



in this scheme

```
     F(1,T) = EXP(-L(0,1)*T)
     F(2,T) = EXP(-L(0,2)*T)
     F(3,T) = EXP(-L(0,3)*T)
    QC(4,T) = S(4,1)*F(1,T) + S(4,2)*F(2,T) + S(4,3)*F(3,T)
```

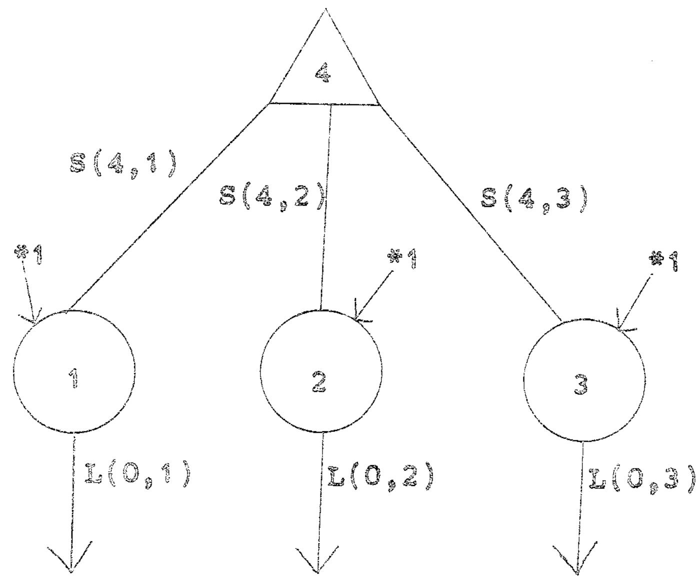
Problem Deck:

```
          1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - 


A SAAM27 MAN002.02           FIT TO SUM OF THREE EXPONENTIALS
2   4    2
C THIS IS EXAMPLE FOR FITTING DATA TO SUM OF 3 EXPONENTIALS, USING
C COMPARTMENTAL MODEL.
H DATA
1 4                                       FSD=.5
C ABOVE CONTROL CARD ASSIGNS FRACTIONAL STANDARD DEVIATION (FSD) OF
C .5 TO ALL DATA.
            .5             .22
            1.0           .049
            1.5           .0112
            3.0           .000330
            6.0           .000360
            8.0           .000430
            10.           .000490
            12.           .000540
            14.           .000575
            16.           .000610
            18.           .000630
            20.           .000650
            30.           .000675
            50.           .000610
H LAM
   L(0,1)   3.                            5.
   L(0,2)   .1                            5.
   L(0,3)   .0067                         5.
C INITIAL ESTIMATES FOR L(0,J) REQUIRED.
H SIG
   S(4,1)                 -100.           100
   S(4,2)                 -100.           100.
   S(4,3)                 -100.           100.
C INITIAL ESTIMATES FOR S(I,J) NOT REQUIRED.
H INI
    1       1.
    2       1.
    3       1.

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - 
12345678901234567890123456789012345678901234567890123456789012345678901234567890
          1         2         3         4         5         6         7         8
```

Problem: Fit composite radioactive sample decay data to linear combinations of 3 isotopes with half-lives 13 hrs., 60 days, and 8.05 days.

Method: Compartmental Model

Schematic:



SAAM Notation:

QC(4,T) = S(4,1)*F(1,T) + S(4,2)*F(2,T) + S(4,3)*F(3,T)

Problem Deck:

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - 


A SAAM27 MAN02.03           LINEAR COMBINATION OF ISOTOPES
C SOLUTION METHOD - COMPARTMENTAL MODEL
2   4
H DATA
C TIME IN HOURS
100                                         FSD=.05
   4          15.           .92
   4          50.           .82
   4          70.           .77
   4          100.          .71
   4          300.          .44
   4          450.          .33
   4          700.          .23
   4          1000.         .17
   4          3000.         .057
   4          2500.         .072
   4          4000.         .035
H LAM
C I-123 HALF-LIFE=13. HOURS. DECAY CONST=.0533/HOUR
C I-125 HALF-LIFE=1440 HOURS=60. DAYS. DECAY CONST=.000481/HOUR
C I-131 HALF-LIFE=193.2 HOURS=8.05 DAYS.  DECAY CONSTANT=.00359/HOUR
 L(0,1)       .0533
 L(0,2)       .00359
 L(0,3)       .000481
H SIG
 S(4,1)                                     1.
 S(4,2)                                     1.
 S(4,3)                                     1.
H INI
    1         1.
    2         1
    3         1.

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - 
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

Fit: Special function:

$$f(t) = K_1 + K_2 t + K_3 e^{-Lt}$$

SAAM
Method: G-function

G(1) = K(30) + K(31)*T + K(32)*EXP(-P(1)*T)

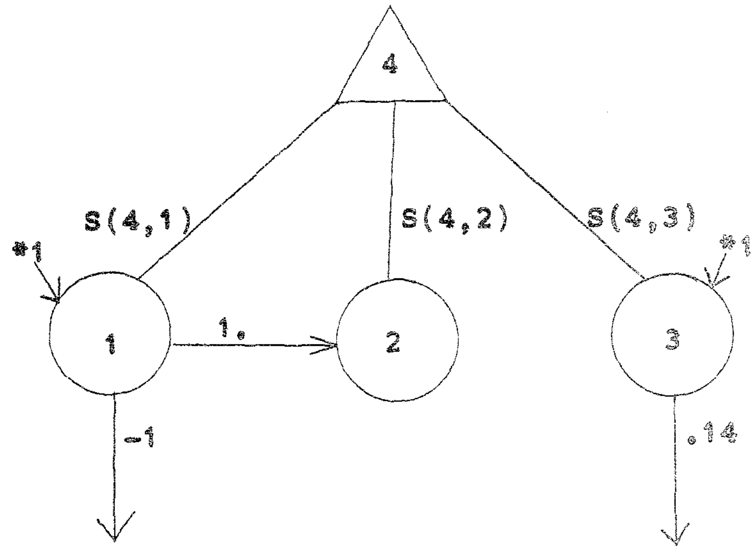
NOTE: Choice of component numbers and subscripts is arbitrary.

Problem Deck:

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
--------------------------------------------------------------------------------


A SAAM27 MAN 1.04            FIT SPECIAL T AND EXPONENTIAL FUNCTION (G-FUNCTION)
2            10                                  4
4  4     1
C LINEAR PLOT CALLED FOR BY 4 ENTRY IN COL 4 OF CARD 4
C SPREAD OF VALUES TOO SMALL TO SHOW UP ON LOG PLOT
H DATA
C DATA OBTAINED ON R.R. 16 JUL 1969
1 5 G(1)                                    SD=.02
X G(1)=K(30)+K(31)*T+K(32)*EXP(-P(1)*T)
            3.0           55.693
            9.0           55.680
            15.0          55.642
            21.0          55.607
            27.0          55.577
            33.0          55.537
            39.0          55.483
            45.0          55.441
            51.0          55.393
            57.0          55.353
            63.0          55.312
            69.0          55.281
            75.0          55.237
            81.0          55.190
            87.0          55.142
            93.0          55.105
H LAM
 P(1)       .14           .01            1.
H SIG
 K(30)                    -1000.         1000.
 K(31)                    -1000.         1000.
 K(32)                    -1000.         1000.

--------------------------------------------------------------------------------
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

<u>Alternate Method of Solution</u>: Compartmental model

<u>Schematic</u>:



In this scheme: F(1,T) = 1.

F(2,T) = T

F(3,T) = EXP(-L(0,3)*T)

QC(4,T) = S(4,1)*F(1,T) + S(4,2)*F(2,T) + S(4,3)*F(3,T)

Problem Deck:

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
--------------------------------------------------------------------------------


A SAAM27 1.042             FIT SPECIAL T AND EXPONENTIAL FUNCTION
C COMPARTMENTAL MODEL METHOD
2
4
H DATA
C DATA OBTAINED ON R.R. 16 JUL 1969
104                                  SD=.02
              3.0        55.693
              9.0        55.680
             15.0        55.642
             21.0        55.607
             27.0        55.577
             33.0        55.537
             39.0        55.483
             45.0        55.441
             51.0        55.393
             57.0        55.353
             63.0        55.312
             69.0        55.281
             75.0        55.237
             81.0        55.190
             87.0        55.142
             93.0        55.105
H LAM
 L(2,1)     1.
 L(0,1) = -L(2,1)
 L(0,3)     .14          .01          1.
H SIG
 S(4,1)                  -100.        100.
 S(4,2)                  -100         100.
 S(4,3)                  -100.        100.
H INI
   1        1.
   3        1.

--------------------------------------------------------------------------------
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

Fit: Linear combination of spectra

In this example, a composite spectrum, represented as data for component 4 is fitted as a linear combination of two given spectra, represented by components 2 and 3. A constraint is introduced in the fitting that the sum of the derived coefficients values for the linear combination be 0.5.

SAAM
Method of Solution: Model type 5.

```
QC(4,T) = S(4,2)*F(2) + S(4,3)*F(3)
```

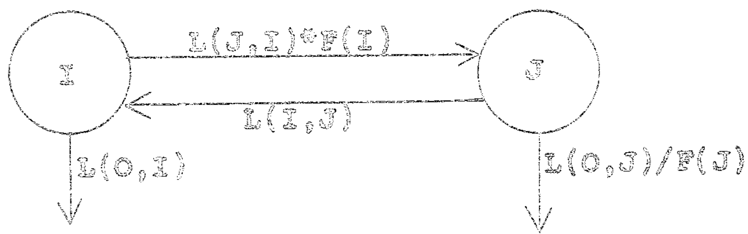
Problem Deck:

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

A SAAM27 MANX05.01              LINEAR COMBINATION OF SPECTRA
    4                                                          5
H DATA
100                                                   SD=.1
C COMPONENT 2 ARE DATA FOR KNOWN SPECTRUM 1
  2            1.             1.9
  2            2.             1.7
  2            3.             1.4
  2            4.             2.4
  2            5.             1.
  2            6.             .15
  2            7.             0
C COMPONENT 3 ARE DATA FOR KNOWN SPECTRUM 2
  3            1.             2.5
  3            2.             5.3
  3            3.             5.5
  3            4.             2.7
  3            5.             3.4
  3            6.             2.0
  3            7.             .5
C COMPONENT 4 IS COMPOSITE SPECTRUM
  4            1.             1.1
  4            2.             1.6
  4            3.             1.5
  4            4.             1.2
  4            5.             1.1
  4            6.             .5
  4            7.             .1
C NOTE ALL SPECTRA HAVE IDENTICAL SET OF T VALUES.
H SIG
   4    3                                             100.
   S(4,3)+S(4,2)=.5

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

NON-LINEAR DIFFERENTIAL EQUATIONS

These equations are formulated in SAAM through the use of FUNCTION-DEPENDENCE on the L(I,J). These functions can be F(I) or G(I), the latter being defined by the user. The FUNCTION-DEPENDENCE permits the introduction of control in compartmental models.

Schematic:



is interpreted as

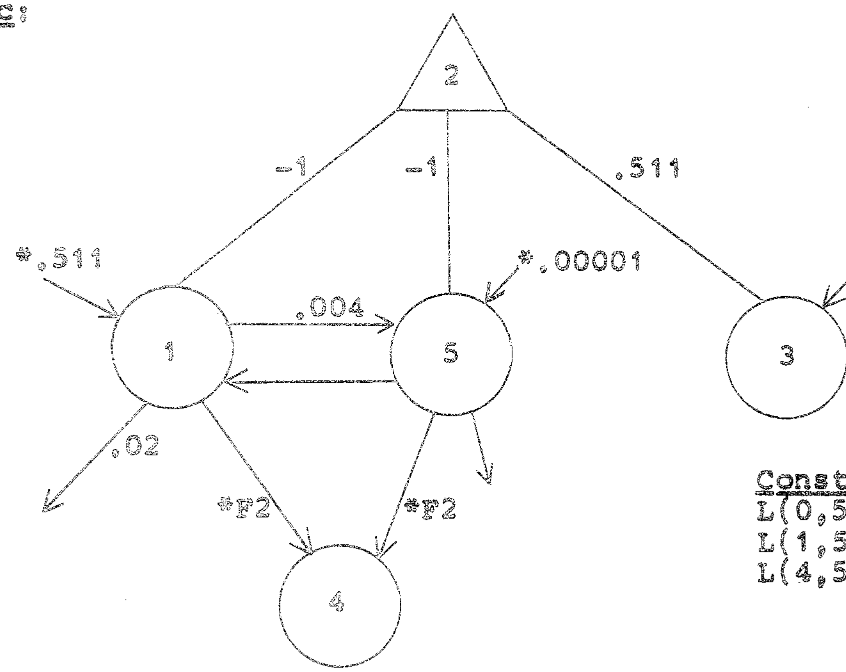
$$dF(I)/dT = -L(J,I)*F(I)*F(I) - L(O,I)*F(I) + L(I,J)*F(J)$$

$$dF(J)/dT = L(J,I)*F(I)*F(I) - L(I,J)*F(J) - [L(O,J)/F(J)]*F(J)$$

$$= L(J,I)*F(I)*F(I) - L(I,J)*F(J) - L(O,J)$$

Simulate: Non-linear compartmental model

Schematic:



Constraints:
L(0,5) = L(0,1)
L(1,5) = 2*L(5,1)
L(4,5) = L(4,1)

Differential Equations:

dF(1)/dT = -.004*F(1) - .02*F(1) + .1*F(1)*F(2) + L(1,5)*F(5)

dF(5)/dT = .004*F(1) - L(1,5)*F(5) + L(4,5)*F(2)*F(5) - L(0,5)*F(5)

dF(3)/dT = 0

QC(2,T) = .511*F(3) - F(1) - F(5)

F(1,0) = .511

F(5,0) = .00001

F(3,0) = 1.

Problem Deck:

```
             1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


A SAAM27 MAN 1.03            NON-LINEAR COMPARTMENTAL MODEL
4  2  1  11
C ABOVE CARD REQUESTS SPECIAL PRINTOUTS
H DATA
1 1
            .0001
            .001
            .01
1 1                                     SD=.1
             2.            .502
             12.           .467
             32.           .428
             52.           .400
             72.           .379
1 5                                     SD=.1
             2.5           .0055
             12.5          .0235
             32.5          .050
             52.5          .073
             72.5          .0905
H INITIAL
    1        .511
    3        1.
    5        .00001
H LAM
  L(5,1)    .004          .002           .05
C L(5,1) IS ENTERED AS ADJUSTABLE PARAMETER WITH LIMITS.  SINCE NO
C INTERATIONS WERE REQUESTED THIS NON-LINEAR PARAMETER WILL NOT ADJUST.
  L(1,5)=2.*L(5,1)
  L(0,1)    .02           0.             0.2
  L(0,5)=L(0,1)
  L(4,1)    -0.1          -0.3           0.             *F2
  L(4,5)=L(4,1)                                         *F2
C NOTE THAT EVEN THOUGH L(4,5) = L(4,1) THE FUNCTION-DEPENDENCE ENTRY
C *F2 IS STILL REQUIRED.
H SIG
  S(2,1)    -1.
  S(2,5)    -1.
  S(2,3)    .511

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
12345678901234567890123456789012345678901234567890123456789012345678901234567890
             1         2         3         4         5         6         7         8
```

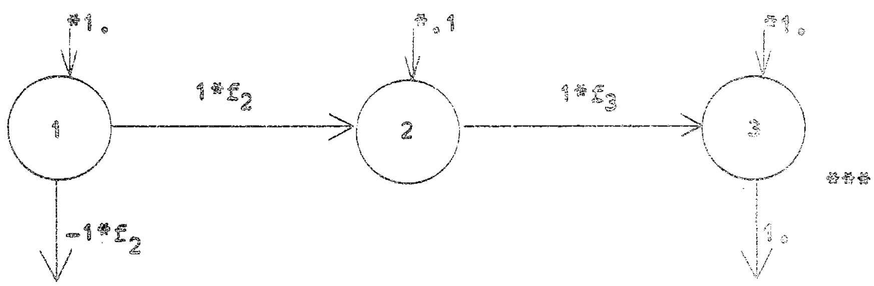
<u>Simulate</u>: Lotka Oscillator

$$df_1/dt = 0 \qquad f_1(0) = 1$$

$$df_2/dt = f_2 - f_2 f_3 \qquad f_2(0) = .1$$

$$df_3/dt = f_2 f_3 - f_3 \qquad f_3(0) = 1.$$

<u>Schematic</u>:



<u>Problem Deck</u>:

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

A SAAM27 MAN001.01            LOTKA OSCILLATOR  SIMULATION EXAMPLE
H DATA
 2.
2        1.                            10.
 3.
2        1.                            10.
H INI
    1    1.
    2    .1
    3    1.
H LAMBDA
  L(2,1)   1.                                      *F 2
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
  L(0,1)   -1.                                     *F 2
C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
  L(3,2)   1.                                      *F 3
  L(0,3)   1.

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

Simulate: Sine function

$$q = 1.2 \sin (3t+.5)$$

using a compartmental model.

It can be shown that the differential equations,

$$df_1/dt = f_2$$

$$df_2/dt = -w^2 f_1$$

with initial conditions $f_1(0) = A \sin\theta$, $f_2(0) = Aw \cos\theta$ yields the solutions,

$$f_1 = A \sin(wt+\theta)$$

$$f_2 = Aw \cos(wt+\theta)$$

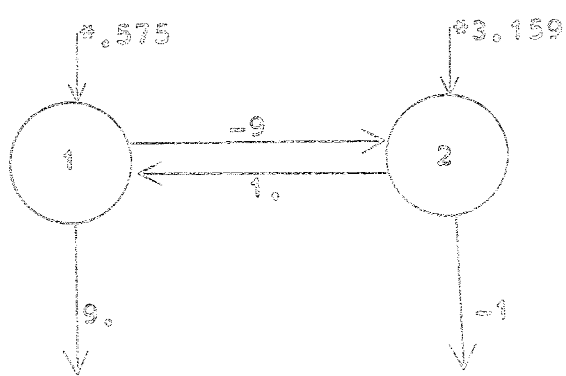
Hence,

$$df_1/dt = f_2 \qquad f_1(0) = 1.2 \sin.5 = .575$$

$$df_2/dt = -9f_1 \qquad f_2(0) = 3.6 \cos.5 = 3.159$$

will yield the desired function as $f_1(t)$.

Schematic:



The pathways $L_{01} = 9$ and $L_{02} = -1$ were introduced to satisfy the differential equations.

SAAM
Problem Deck:

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


A SAAM27 MAN                     SIMULATE SINE FUNCTION (COMPARTMENTAL MODEL)
4  4      1
C 4 IN COLUMN 4 CALLS FOR AN ONE PAGE LINEAR PLOT.
H PAR
   IC(1)    .575
   IC(2)    3.159
   L(0,1) = -L(2,1)
   L(0,2) = -L(1,2)
   L(2,1)   -9.
   L(1,2)   1.
H DAT
C NOTE ALL PARAMETERS ARE ENTERED UNDER H PAR HEADING.
C COMPONENT 1=1.2*SIN(3T+.5)
101
            0.
2           .1                            40.
102
            0.
2           .1                            40.

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

Simulate:

$$q_1 = 10\ f_1$$

$$q_2 = f_2$$

$$q_7 = f_1 + .5\ f_2$$

where f_1 and f_2 are the solutions of

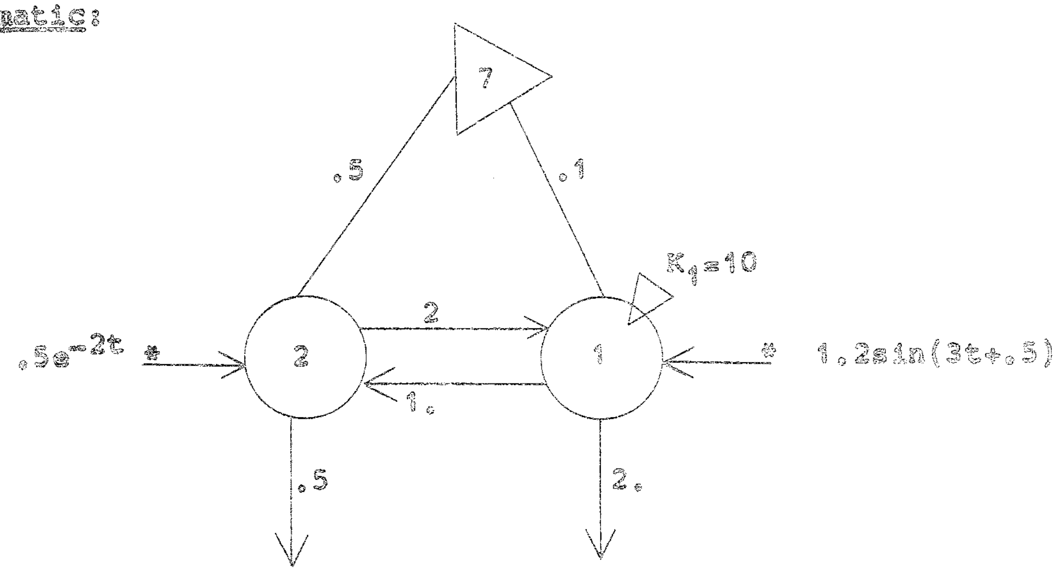
$$df_1/dt = -3\ f_1 + 2\ f_2 + 1.2\ \sin(3t+.5)$$

$$df_2/dt = 1\ f_1 - 2.5\ f_2 + 0.5e^{-2t}$$

$$f_1(0) = 0 \qquad f_2(0) = 0$$

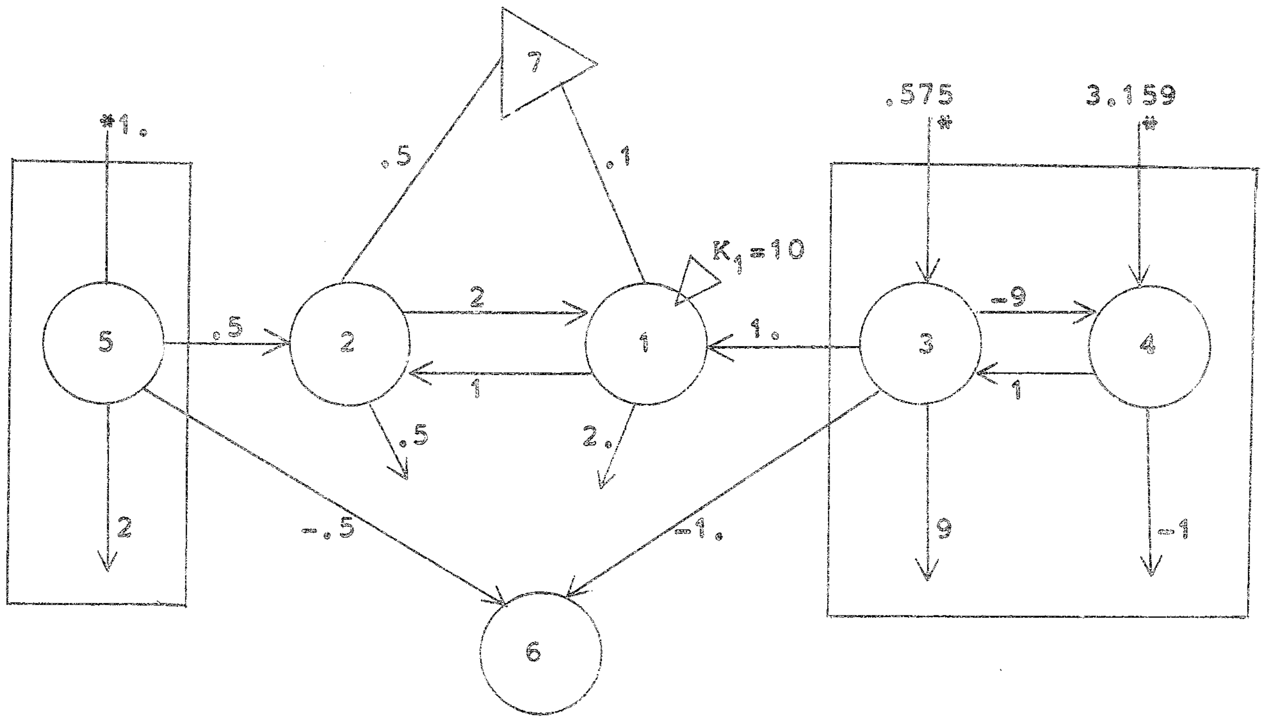
Simulate above from t=0 to t=3, then cut off inputs to f_1 and to f_2. Reset time scale to 0 and observe solution for 3 more units of time. Obtain values for q_1 and q_2 in intervals of .1 units of time over entire simulation period and values for q_7 in intervals of .1 units of time over last period only.

Schematic:



SAAM:

The input functions may be generated by compartmental subsystems (see previous example), yielding the following total system schematic:



Component 6 is a 'dummy' to provide termination for the compensating pathways L(6,5) and L(6,3).

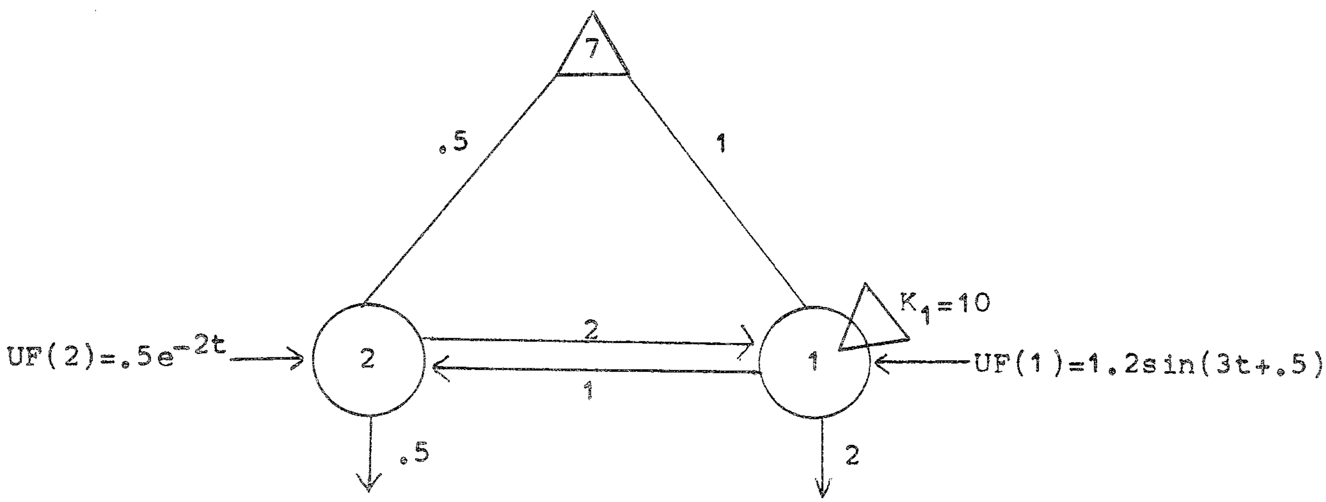
The disruption of the inputs is simulated in SAAM by the use of a TC(1) interrupt. The index 1 is arbitrary.

Problem Deck:

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

A SAAM27 MAN 1.05          SIMULATE DIFF EQUAT W/SIN AND EXP INPUTS
2   7                                            1
C 1 ENTRY IN COLUMN 50 OF THE ABOVE CARD REQUESTS RUNGE-KUTTA SOLUTION
C METHOD.
H DAT
 1.         0.
2           .1                      30.
 2.
2           .1                      30.
H DAT                     TC(1)
   T        0.
C ABOVE ENTRY RESETS TIME SCALE TO ZERO.
 1.
2           .1                      30.
 2.
2           .1                      30.
 7.         0.
2           .1                      30.
H INI
   3        .575
   4        3.159
   5        1.
H KAP
   1        10.
H LAM
 L(1,2)     2.
 L(2,1)     1.
 L(0,1)     2.
 L(0,2)     .5
 L(3,4)     1.
 L(4,3)     -9.
 L(0,3)     9.
 L(0,4)     -1.
 L(1,3)     1.
 L(6,3) = -L(1,3)
 L(0,5)     2.
 L(2,5)     .5
 L(6,5) = -L(2,5)
H SIG
 S(7,1)     1.
 S(7,2)     .5
H PCC                     TC(1)
C THESE PARAMETERS ARE RESET AT T-INTERRUPT.
   1    3                 0.
   2    5                 0.

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

ALTERNATE METHOD OF SOLUTION: Use of UF

Schematic:



Problem Deck:

```
                  1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

A SAAM27 MAN10,05                   SIM. DIFF. EQ WITH SIN & EXP INPUT
H DAT
XUF(1)=P(1)*(1.2*SIN(3*T)+.5)
XUF(2)=P(2)*.5*EXP(-2*T)
101
            0
2           .1                            30
102
            0
2           .1                            30
H DAT                         TC(1)
  T         0
101
            0
2           .1                            30
102
            0
2           .1                            30
107
            0
2           .1                            30
H PAR
   L(2,1)   1
   L(1,2)   2
   L(0,1)   .5
   L(0,2)   2
   K(1)     10
   S(7,1)   1
   S(7,2)   .5
   P(1)     1
   P(2)     1
H PCC                         TC(1)
 P  1       0
 P  2       0

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

SIMILARITY TRANSFORMATION: (Option B)

Given the matrix,

$$M = \begin{vmatrix} 3 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 1 \end{vmatrix}$$

and the matrix L, having the following constraints,

$L(1,1) = .375$ $L(1,2) = .25$ $L(1,3) = .375$

$L(2,1) + L(3,1) = -.375$

$L(2,2) + L(3,2) = 0$

$L(2,3) + L(3,3) = .375$

$L(3,1) = 0$ $L(3,2) = -.5$ $L(3,3) = .5$

calculate the similar matrix F:

$F = LML^{-1}$

SAAM
Method of Solution: Use model type 3.

Problem Deck:

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
--------------------------------------------------------------------------------

A SAAM27                                SIMILARILTY TRANSFORMATION - OPTION A
2                                                         3                   1
4         1
H MAT
   3    3    1    1   -1.
   3    3    2    2 -2.
   3    3    3    3 -3.
   26
H LAM
 L(1,1)        1.
 L(1,2)       1.
 L(1,3)       1.
 L(2,1)       -1.
 L(2,2)       -2.
 L(2,3)       -3.
 L(3,1)       1.
 L(3,2)       4.
 L(3,3)       9.
H DAT
  1           0.01
  1           0.02
  1           0.03

--------------------------------------------------------------------------------
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

Problem Deck:

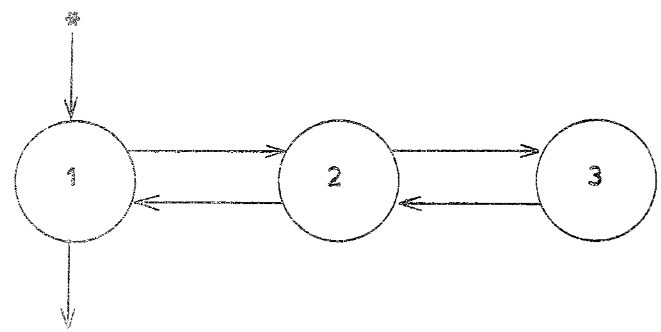
```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
--------------------------------------------------------------------------------


A SAAM27 MANX03.01            SIMILARITY TRANSFORMATION - OPTION B
2  3                                                   3
3                            .01            .98                 .98
4       1
H DAT
  1       1.01                              .01
H LAM
 L(1,1)=.375
 L(1,2)=.25
 L(1,3)=.375
 L(2,1) + L(3,1) = -.375
 L(2,2) + L(3,2) = 0
 L(2,3) + L(3,3) = .375
 L(3,1)=0.
 L(3,2)=    -.5
 L(3,3) =    .5
H MAT
   3    3    1    1  3.
   3    3    2    2  2.
   3    3    3    3  1.
  26

--------------------------------------------------------------------------------
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

MAPPING TO 3 COMPARTMENT MODEL

Given that the response of a compartment to a unit impulse is

$$f_1 = .5146e^{-10.42t} + .0718e^{-1.565t} + .4136e^{-.0873t}$$

derive the solution for a compartment series model with a loss from compartment 1 only, using a similarity transformation:



(Berman, Shoenfeld: 1956)

It is known that the model parameters are related to the eigenvalue-eigenvectors through the relation,

$$F = LML^{-1}$$

where F is the matrix of parameter values, L is the matrix of eigenvectors (coefficients of exponential components) and M is the matrix of eigenvalues (exponential constants). (We regret the change of notation here. This is due to the peculiar way the data are handled in SAAM. See model type 3 in Section VI.)

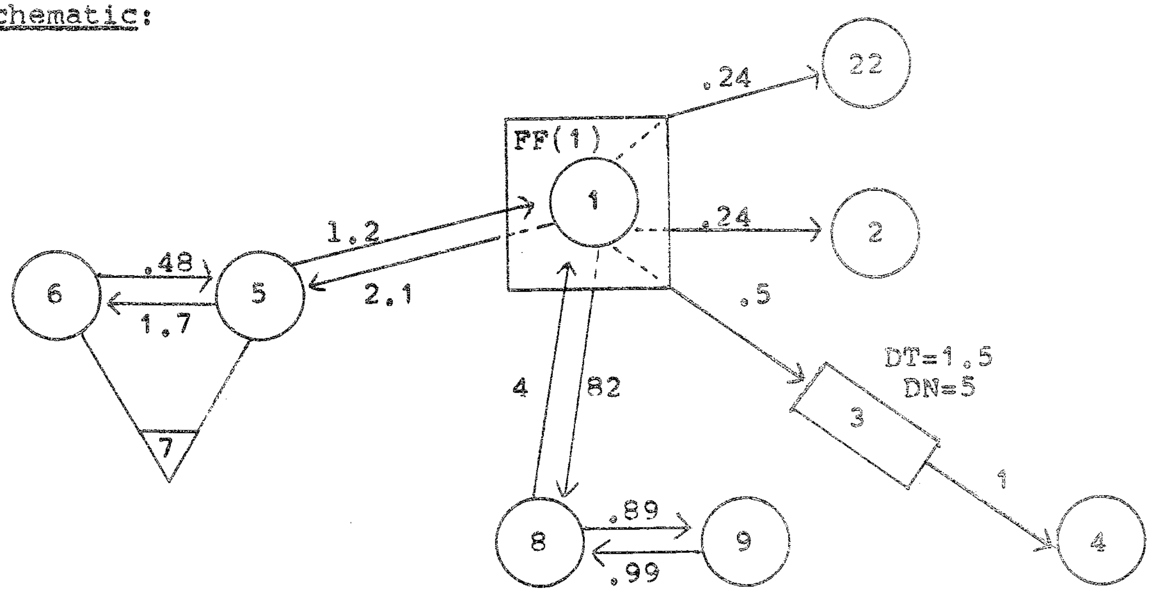
In solving the problem, a number of constraints arise from the initial conditions and the fact that $L_{02} = L_{03} = L_{13} = L_{31} = 0$. These are imbedded as equations in the SAAM problem deck.

Problem Deck:

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
--------------------------------------------------------------------------------


A SAAM27 MANX03.03             SIMILARITY TRF 3 COMP
    3   20                                            3
                     100000.   .01       .999                      .99
          1
H DAT
101                                      SD=.1
C SET UP FOR 3 COMP SERIES MODEL
            .02
            .03
            1.03                         .01
            3.01                         .01
H LAM
   L(1,1)   .5146
   L(1,2)   .0718
   L(1,3)   .4136
C  G(1) ARE THE EXPONENTIAL CONSTANTS
  G(1)=10.42
  G(2)=1.565
  G(3)=.0873
  G(4)=L(1,1)*G(1)+L(1,2)*G(2)+L(1,3)*G(3)
C G(4) IS A CALCULATION OF F(1,1), USED IN SUBSEQUENT CONSTRAINTS.
  G(5)=1/(L(1,1)/G(1)+L(1,2)/G(2)+L(1,3)/G(3))
C G(5) CALCULATES F(0,1) FOR SUBSEQUENT USE.
   L(2,3)   .4                           1.
C L(2,3) IS ONLY INDEPENDENT PARAMETER LEFT TO CALCULATE.
  L(3,1)+L(3,2)+L(3,3)=0
C ABOVE IS INITIAL CONDITION CONSTRAINT
 L(3,1)*G(1)+L(3,2)*G(2)+L(3,3)*G(3)=0
  L(2,1)+L(2,2)+L(2,3)=0
 L(2,2)+L(3,2)=L(1,2)*G(5)/G(2)-L(1,2)
 L(2,3)+L(3,3)=L(1,3)*G(5)/G(3)-L(1,3)
C OTHER CONSTRAINTS
C EXPONENTIAL CONSTANTS ENTERED AS MATRIX
H MAT
   3    3    1    1 10.42
   3    3    2    2 1.565
   3    3    3    3 .0873
  26

--------------------------------------------------------------------------------
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

FORCING FUNCTION (FF), DELAY ELEMENT (DT, DN) AND QO: Example

Schematic:



SAAM

1. Forcing Function

   a. FF(1) forces the values of F(1,T) as seen by all other compartments in the system to be equal to FF(1,T). This feature tends to decouple subsystem so that adjustment of parameter values in one has minimal effect on the responses of other subsystems.

   b. The value of F(1,T) is calculated in the normal manner, i.e., it is independent of the forcing function FF(1,T). In this way, F(1,T) may be reconstructed separately and used as such for data fitting. (In this example the subsystems do not adequately reconstruct F(1,T).)

2. Delay Line

   a. DT(3) is the mean time of the delay element. Thus the rate of entry into the delay element at time T is approximately the same as the rate of exit at time T+DT(3).

   b. DN(3) is the number of discrete cells in the delay element each with a resident time of DT(3)/DN(3) = .3 days. This also serves as the resolution time of the element.

3. QO

   In this example the QO is used to permit the simulation of individual urine samples by resetting F(22) to zero at the indicated times of collection.

Problem Deck: X-27 Oct 1976

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
A SAAM27 MAN 8.10             EXAMPLE: FF, DELAY FLT & QO
H DAT
XFF(1)=.778*EXP(-175.5*T)+.1745*EXP(-74.9*T)+
 .020*EXP(-8.69*T)+.01685*EXP(-.123*T)
XG(8)=F(8)+F(9)+.2*(FF(1)+F(7))
101      /1440
         0
101      /1440                        FSD=.1
         3         .77
         10        .37
         30        .09
         60        .04
         120       .03
         240       .02
         300       .02
101                                   FSD=.1
         1         .015
         3         .012
         4         .010
102      /24                          FSD=.1
C  XXXXXX  CUMULATIVE URINE  XXXXXXXXXX
         4         .003
         16        .005
         32        .007
         68        .012
         116       .017
122      /24                          FSD=.1
C  XXXXXX  INDIVIDUAL URINE SAMPLES  XXXXXXXXXXXX
         4         .003
         16        .002
         32        .002
         68        .005
         116       .005
12200    /24
         4
         16
         32
         68
         116
104
C  XXXXXX  CUMULATIVE FECES  XXXXXXXXXX
         1         .0007
104                                   FSD=.1
         2         .009
         3         .016
         4         .023
         5         .029
107      /1440                        FSD=.1
C  XXXXXX  RED BLOOD CELLS  XXXXXXXXXXX
         3         .004
         10        .090
         30        .014
         60        .016
         120       .018
         240       .021
         300       .021
```

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

107                                     FSD=.1
           1           .036
           3           .055
           5           .062
108G(8)    /1440                        FSD=.1
C  XXXXXX  LIVER  XXXXXXXXXX
           2           .263
           10          .424
           30          .555
           60          .594
           120         .604
           240         .588
           300         .578
108G(8)                                 FSD=.1
           1           .539
           3           .544
           5           .460
125FF(1)   /1440
C  XXXXXX  FORCING FUNCTION  XXXXXXXXX
           0
           3           .77
           10          .37
           30          .09
           60          .04
           120         .03
           240         .02
           300         .02
125FF(1)
           1           .015
           3           .012
           4           .010
H PAR
   L(2,1)    .24
   L(22,1)=L(2,1)
   L(0,1)=-L(2,1)
   L(3,1)    .5
   DT(3)     1.5
   DN(3)     5
   L(4,3)    1
   L(8,1)    82
   L(1,8)    4
   L(8,9)    .89
   L(9,8)    .99
   L(5,1)    2.1
   L(1,5)    1.2
   L(6,5)    1.7
   L(5,6)    .48
   S(7,5)    1
   S(7,6)    1

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

DECONVOLUTION SCHEME:

Problem: Suppose for a given system one has the response $w(t)$ to a unit impulse, and the response $r(t)$ to an unknown input $u(t)$. The problem is to find the unknown input $u(t)$.

Solution: If the system is linear with time independent coefficients, then $r(t)$ and $u(t)$ are related through the convolution integral,

$$(1) \quad r(t) = \int_0^t u(X)\, w(t-X)\, dX$$

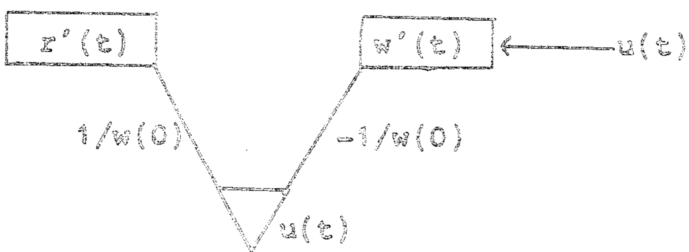
where X is the dummy variable of integration. Knowing $w(t)$ and $r(t)$, one can solve equation (1) for $u(t)$; the mathematical technique is called deconvolution.

The following method (Berman, unpublished) may be used to solve for $u(t)$ using SAAM. Equation (1) may be rewritten (by differentiating the integral) as

$$(2) \quad u(t) = [1/w(0)]\, [r'(t) - \int_0^t u(X)\, w'(t-X)\, dX].$$

where $w(0) \neq 0$.

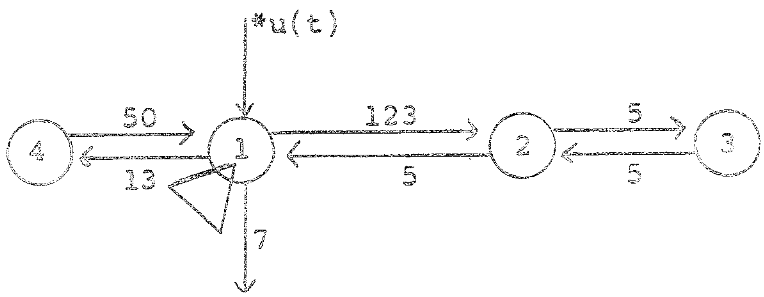
The solution of equation 2 can be obtained by SAAM according to the following schematic:



Example: In this example, some motivation for each step is given to facilitate the extention of this method to other problems. The theory behind the technique and a more general development will be given elsewhere.

Apr 15,1977
rev Feb 1,1978

Suppose we are given the following compartmental model and the observed response for compartment 1 for some unknown input u(t) into compartment 1. The problem is to find u(t), (in SAAM notation, UF(1)).



Step 1. Calculate $r'(t)$

Fit the response data r(t) to a sum of exponentials. In this example,

$$r(t) = .0075e^{-263t} - .02e^{-66t} + .007e^{-2.4t} + .0054e^{-.025t},$$

hence,

$$r'(t) = -1.97e^{-263t} + 1.32e^{-66t} - .017e^{-2.4t} - .00014e^{-.025t}.$$

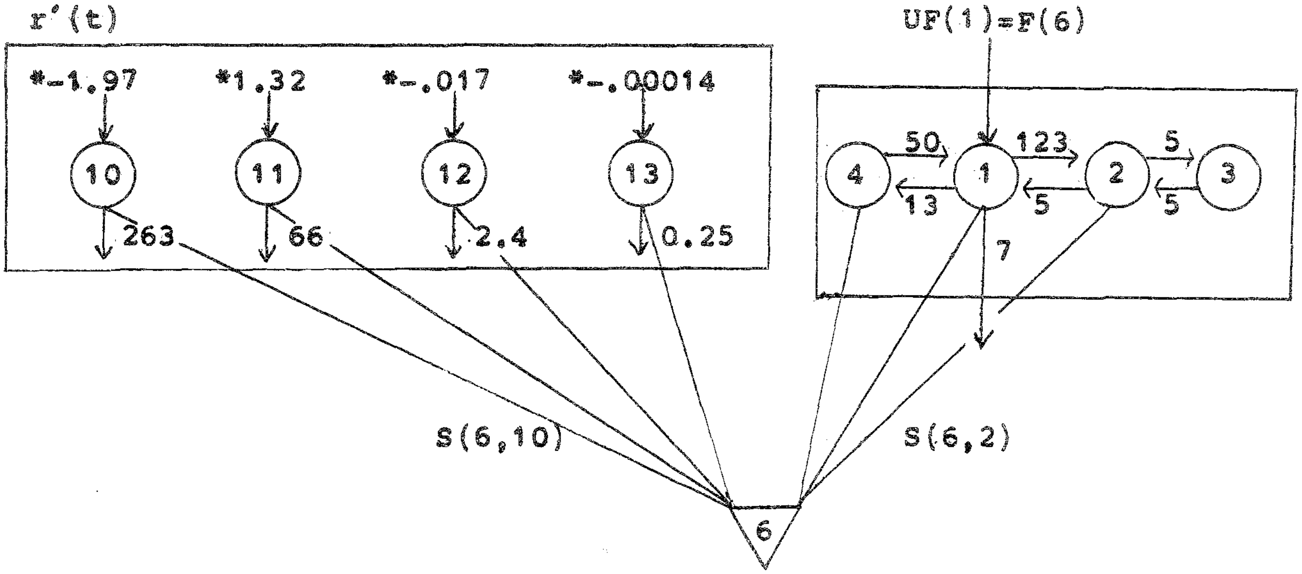
Step 2. Generate the w'-system

For the above example, notice that w(t) is the response in compartment 1 for IC(1) = 1, i.e., w(t) = F(1). Thus,

$$w'(t) = dF(1)/dt = -(L(4,1) + L(2,1) + L(0,1))\ F(1)$$

$$+ L(1,2)\ F(2) + L(1,4)\ F(4).$$

Step 3. Set up the general schematic for the solution for this particular example.



where the summers are defined:

$S(6,1) = [-1/w(0)]\ [L(1,1)] = [-1/w(0)]\ [-L(0,1)-L(2,1)-L(4,1)]$

$S(6,2) = [-1/w(0)]\ L(1,2)$

$S(6,4) = [-1/w(0)]\ L(1,4)$

$S(6,10) = S(6,11) = S(6,12) = S(6,13) = 1/w(0)$

Hence, a summer with coefficients $S(I,J)$ equal to the coefficients of the $F(J)$ converts the w-system to a w'-system. The desired solution $u(t)$ is the generated function $F(6)$. Values for $F(6)$ at descrete time points must be specifically requested by the user (see problem deck). The calculated $F(6)$ values can be fitted to a mathematical function thereby giving an approximation to $u(t)$ as an analytic expression. In this example,

$$u(t) = -2.5e^{-65t} + .77e^{-40t} + 1.7e^{-5t} - .004e^{-.05t}$$

Step 4. Check goodness of derived $u(t)$.

By entering the observed data for $r(t)$ in compartment 1 it is possible to see directly how well the solution $F(6) = UF(1)$ will generate the observed values (see problem deck).

Comments:

1. Equation (2) is valid only if $w(0) \neq 0$. For the case when $w(0)=0$, higher order derivatives must be obtained.

2. The scheme is more general than indicated in this example. For the case where $w(t)$ is given directly and a compartmental model is used to simulate it, the input, $u(t)$, for the w'-system must parallel that used for the w-system.

3. It is important to realize that in deconvolution the goodness of the derived function $u(t)$ is greatly dependent on $r'(t)$, and in particular on $r'(0)$.

The problem deck follows.

Problem Deck:

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

A SAAM27 MAN                        EXAMPLE: DECONVOLUTION SCHEME
H DAT
C  F(6) IS THE DESIRED SOLUTION U(T).
C  UF(1) = F(6).  SEE EXPLANATION IN TEXT.
XUF(1)=F(6)
C  THE FOLLOWING ARE THE OBSERVED VALUES R(T) FOLLOWING THE UNKNOWN INPUT.
101        /1440
C  XXXXXX  TIME UNITS ARE MINUTES   XXXX
            0              0
            10             .920-03
            20             .443-02
            30             .709-02
            45             .940-02
            60             .105-01
            90             .111-01
            120            .110-01
            180            .106-01
            240            .101-01
            300            .965-02
101
C  XXXXXX  TIME UNITS ARE DAYS   XXXXXXX
            1              .595-02
            2              .522-02
            3              .505-02
            4              .492-02
C  THE FOLLOWING ARE REQUESTED VALUES OF F(6) AT DISCRETE TIMES
C  TO 'SHOW' THE SOLUTION.
106        /1440
C  XXXXXX  TIME UNITS ARE MINUTES   XXXX
            0
            5
            10
            15
            20
            30
            45
            60
            90
            120
            180
            240
            300
            360
106        /24
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

C  XXXXXX  TIME UNITS ARE HOURS  XXXXXX
            8
            10
            12
            15
            18
            24
            36
106
            2
            3
            4
            5
H PAR
C  P(1) IS THE VALUE FOR W(0).
   P(1)      1.
C
C  W'-SYSTEM. RATE CONSTANTS IN UNITS OF RECIPROCAL DAYS.
   L(2,1)   .123
   L(1,2)    5
   L(2,3)    5
   L(3,2)    5
   L(4,1)    13
   L(1,4)    50
   L(0,1)    7
C  THESE SUMMERS CONVERT THE W-SYSTEM TO THE W'-SYSTEM.
   S(6,1)=-(-L(0,1)-L(2,1)-L(4,1))/P(1)
   S(6,2)=-L(1,2)/P(1)
C  S(6,3)=0 BECAUSE L(1,3)=0 AND THEREFORE WAS NOT ENTERED.
   S(6,4)=-L(1,4)/P(1)
C
C  R'-SYSTEM.
   L(0,10)   263
   L(0,11)   66
   L(0,12)   2.4
   L(0,13)   .025
   IC(10)    -1.976
   IC(11)    1.319
   IC(12)    -.017
   IC(13)    -.00014
C  THESE PARAMETERS GENERATE THE R'(T)/W(0) PORTION OF THE
C  DECONVOLUTED FUNCTION U(T).
   S(6,10)=1/P(1)
   S(6,11)=1/P(1)
   S(6,12)=1/P(1)
   S(6,13)=1/P(1)

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

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FORMATS

HEADINGS FORMAT

	Name and Operation		Segment	Index TC ( )	OUT LIB	I/O Unit		Initials	Number
1 2 3	4 5	7-9	13-25	27 - 40	47-49	50	51	53 - 55	56-63
H									

DATA FORMAT

F1	Field 2	Field 3	Field 4	Field 5	Field 6		Field 7
	Categ or instruct.	T	Observed value	Statist. weight			Theta
1 2 3	4 - 11	13 - 25	27 - 40	42 - 55	56 - 59	60	62 - 72

PARAMETER FORMAT

	Field 1	Field 2	Field 3	Field 4	Field 5		Field 7
	Parameter	Initial Value	Minimum Value	Maximum Value	Fn-dep		SD
1 2 3	4 - 11	13 - 25	27 - 40	42 - 55	56 57 58 59	60	62 - 72

MATRIX FORMAT

	Matrix Dimension	1st entry Indices	1st entry in	2nd entry in	3rd entry in	4th entry in
	rows cols	row I, col J	(I,J)	(I,J+1)	(I,J+2)	(I,J+3)
1 2 3	4 ... 8 9	13 14 ... 18 19	21 - 32	34 - 45	47 - 58	60 - 71

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S E C T I O N XII

APPENDIX

CARD 1

	Program VERSION	Problem I.D.		Instructions		User's name and other comments
		Initials	Number			
1	3 → 8	10 → 12	13 → 20	22→24	26→30	31 →
A	SAAM25					

CARD 2 (OPTIONAL)

	Number of Comps.	Number of Itera- tions	Problem Requested				Model Code	Specials				
			Location		I.D. of Problem							
			INP OUT LIB	UNIT (if LIB)	Initials	Number	(L50)	(L55)	(L60)	(L65)	(L70)	
1	4 → 5	9 → 10	17 → 19	20 → 21	23 → 25	26 → 33	49 → 50	51→55	56→60	61→65	66→70	73 → 80

CARD 3 (OPTIONAL)

	TIME FACTOR (decimal)		P (decimal)	P_1 (decimal)	E (decimal)	PREC (decimal)	CONMIN (decimal)	
1	2 → 10	11 → 20	21 → 30	31 → 40	41 → 50	51 → 60	61 → 70	73 → 80
				.01	.98		.98	

CARD 4 (OPTIONAL)

	Covari- ance Matrix	Partials Matrix	Plot	A- Matrix	Inter- mediate Results	Reorgan- ized Problem	Res. Vector Calcu- lation	NEWDEK OUTPUT	Zeroeth Iter Solution when NI > 0	Data Deck List		Use Only Critical Points In Fitting	
1	2	3	4	5	6	7	8	9	10	11	12	13	73→80