BUILDING SIMULATION EXTENDED--THE PROCESS CONNECTION

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ABSTRACT-Current hour-by-hour simulation programs treat only simple process energy problems but have a potential for expansion. This paper defines the three basic types of processes that can be analyzed by these programs when adapted to curve-fitting and custom simulation modeling techniques. These techniques are compared and evaluated; the paper concludes that, while not as rigorous as custom simulation, the curve-fitting technique meets most modeling needs of the simpler processes.

INTRODUCTION

In the past year I have explored simulation of several industrial and commercial processes for energy use. The exploration has led me to the conclusion that current hour-by-hour building energy simulation programs offer a great deal when adapted to simulate industrial processes.

The impetus for exploring these areas were client requests for modeling sawmills and grocery stores. All the sawmills used sawdust derived from the cutting process to fire boilers for process and building steam heating and, in some cases, electricity. However, as the sawmill owner improved the efficiency of the sawing operation, the amount of sawdust available for fuel declined and supplemental fossil energy sources, such as natural gas and fuel oil, were required to meet steam needs. Improvements in operational efficiency therefore often cost the owner more to operate the mill than before such improvements were made. This type of system is shown on Figure 1. In the grocery stores, the owner frequently made modifications so that heat rejected from the freezer cases in the store provided general building heat, as shown on Figure 2. Building energy simulation presents the opportunity to determine the economic effect of such changes in energy-using systems for process applications.

The energy-modeling tools now available offer a number of features that custom process simulations do not. Specifically, all commonly used hour-by-hour models include the logic to accumulate energy use by fuel type and to model various primary plant components such as boilers and chillers. Because many processes occur within the confines of a structure, with the usual lighting and heating needs, or on sites with structures served by common utility meters, effective analysis requires the building modeling features included in the hour-by-hour simulation programs.

PROCESS CATEGORIES

In studying building and process simulation it became apparent that there are three general processes, or cases. The simplest of these is a process that consumes energy and rejects or extracts heat to or from a space being analyzed, as shown on Figure 3. The second case is one in which a process generates or extracts energy to or from a space while simultaneously producing heat or a single source of fuel that can be used later to meet the building's energy needs. Figures 4 and 5 show this type of process. The third case is one where multiple sources of energy for later use are obtained from the process, as shown on Figure 6.

PRESENT PROGRAM CAPABILITIES

Current hour-by-hour simulation programs and some simplified programs generally permit the user to describe a process as part of the thermal LOADS input phase. In this phase the user is prompted to define the operating schedule of the process, its thermal (sensible heat) and airborne moisture (latent) contributions to the space, and how these contributions relate the total consumption of the process. In most programs, only heating processes are addressed. Examples of processes that are routinely treated today are in-space computers; copiers; kitchen equipment, including ovens, stoves, and refrigerators; and heat-generating process machinery. Most programs do not address:

1. Process refrigeration systems where the heat extracted from one space is rejected to another space.

2. Processes that include as a byproduct a consumable fuel or fuels or heat that can be used elsewhere on the site.

MEETING PROCESS NEEDS

To meet process needs, the current simulation programs require enhancement beyond their present state of development. The programs treat only simple processes where heat, moisture, or both are given off to a space. To enhance current models, a process module must be developed in the thermal LOADS portion of the programs. This module replaces the present simplified process calculation.

In addition to capturing data about the process itself, the new process module calculates the thermal contribution to the space in which the process is located, and then it saves certain data for later use by either the SYSTEMS portion or the PLANT portion of the simulation program. In the case cited above for the grocery, the data saved are used in the SYSTEMS module of the simulation program to expend "waste" heat from the refrigeration process for heating building air before "new" heat is used from electric or fossil sources. In the case of the sawmill, the amount of wood waste from the cutting process is passed on to the PLANT simulation for use as a fuel by the plant boilers before fossil energy is used.

DEVELOPMENT OF A PROCESS MODULE

There are two basic approaches to meeting the development needs of a process module. One approach is to develop an enhanced curve-fitting module similar in character to the model for process heating used today. The other, more elegant, approach is to develop process-specific modules for each process modeled. A discussion of each approach follows.

Curve-Fitting

A curve-fitting module is one that uses mathematical curves to approximate the relationships between the elements of a process. These curves do not necessarily define the internal detail of a process but, rather, treat it as a "black box." Traditionally, the process modules presently incorporated in simulation programs are structured in this way. For a given space, an amount of process heat or moisture addition, an energy source, a profile of usage, and a percentage of that energy rejected to that space are defined. Such an approach allows the simulation program to determine the heat added hourly to a space as the product of:

Total heat added * percent rejected * profile = space heat addition

Energy accumulated hourly to the primary meter is computed as the product of:

Total heat added * profile = net energy requirement $_{\text{fuel type}}$

To model more elaborate processes by curve-fitting requires some extensions to the above procedures. Principal among these is the need to model various generic process variations, as shown on Figure 7.

This can be done by asking the user to define the energy output as a function of the energy input using a set of three additional terms plus a flag indicating the form of the energy. If the user indicates that the form of the energy is "heat," then it is necessary to indicate the quality (temperature) of the heat.

The procedure I have employed requires the user to perform separately a regression analysis on data relating the output of the process to its energy input and then to input a curve type from a choice of a linear, exponential, logarithmic, or power curve along with two constants "a" and "b," or:

$E_o = a + b * E_i$ (Curve Type 1 - Linear)

$E_o = a * e^{(b*E_i)}$ (Curve Type 2 - Exponential)

$E_o = a + b * \log(E_i)$ (Curve Type 3 - Logarithmic)

$E_o = a * E_i^{\,b}$ (Curve Type 4 - Power curve)

Where:

E_o = Energy delivered from the process

E_i = Energy input to the process

With these data, nearly all single output processes can be modeled with relatively simple enhancements to the computer program code. For conventional processes such as the Case 1 types referred to above, the curve parameters "a" and "b" are set to zero and the equations revert to those now used by most programs.

Custom Coding

Custom coding is the procedure by which a discrete process is modeled in detail. Such a procedure is quite rigorous but very expensive to implement in all but the most frequently used cases. This procedure can be compared to the curve-fitting approach in the same relationship as comparing the microcomputer-based, simplified building energy simulation programs to the detailed hour-by-hour programs.

Using the sawmill problem as an example, the custom-coding approach requires that a discrete subroutine of computer code be prepared and debugged for each sawmill, depending on the number of saws used, the type of logs cut, the moisture content of the logs, the lumber sizes being cut, the number and types of finishing processes being used, whether kiln drying is required, and many other variables. A so-called "subroutine" at this level of detail would rival the size of the mainline simulation program codes. Such an investment might be justifiable for an internal mill model, but it would not suit the cost-performance needs of an engineer, utility, or other third party analyzing the overall energy picture at a multitude of plants.

Case 3 processes, such as paper mills with multiple output streams of usable energy, can be expected to require custom coding in almost every project. The need is caused by the difficulty of defining simple curve-fits of the process outputs and their interrelationships.

Data-Passing Requirements

Regardless of whether process simulation is performed using a curve-fitting procedure or by custom coding, it is necessary to carry some additional information through the simulation for later use. This information includes the quantity of energy in heat units, the type of energy (for example, heat, wood chips, or alcohol), and, in the case of heat, its temperature. Where energy is produced by a process, it is necessary to modify the SYSTEMS and PLANT portions of the simulation programs to accept first those sources of energy internally generated, if their quality is suitable, then traditional sources. These procedures require program modification to indicate which secondary or primary system will be able to use the heat or fuel generated by the process and then to verify how much energy is available for use before conventional energy is used.

DISCUSSION

The ability to model processes extends the function of the building energy simulation programs in the marketplace substantially for a relatively low investment in programming cost. The purist in us all would desire that all models be encoded in the custom mode, yet this level of detail is seldom necessary to allow us to see the relative effects of conservation measures or process operating changes. Figures 8 and 9 gives a summary comparison of the two methods.

Implementation of the curve-fitting technique requires detailed familiarity with the particular hour-by-hour simulation code one intends to modify, but actual coding changes are usually less than 200 lines. Depending on staff costs, this amount of time will translate to costs of from U.S. $2,000 to U.S. $5,000. Such a cost, while not trivial, is far less than the costs to develop a full, new simulation code for the process and permits the engineer to analyze situations that have significantly larger returns on investment than those seen in general-occupancy buildings.

A drawback of the curve-fitting approach is that processes with continuously varying quality conditions of heat output are not modeled well. The use of a fixed quality (temperature) works well for condensing processes but poorly for those whose temperatures vary, such as combustion heat-recovery processes (cooking or dishwasher heat recovery).

CONCLUSIONS

Modeling processes that result in heat or usable energy in other parts of the building's energy envelope extend the capabilities of current hour-by-hour simulation programs. Such processes are of three types: those which generate or absorb heat or moisture in a space, which are treated by today's simulation codes; those which, while rejecting or absorbing heat and moisture in a space, also produce either heat of a given quality or a consumable fuel; and those which produce more than one consumable fuel or heat. These processes can be modeled by two ways, either a curve-fitting method or detailed modeling of the specific process at its location. The costs of writing a iscrete custom model of each process ocation would be comparable to those experienced by the developers of the current generation of simulation programs and would be noncompetitive. This paper suggests that the more cost-effective approach is to extend the curve-fitting approach presently in use to allow modeling of single-output processes. Such techniques, while costing from about U.S. $2,000 to U.S. $5,000 to implement, represent a potential for the engineer to advise effectively a number of clients not now addressed by the modeling tools in the marketplace.

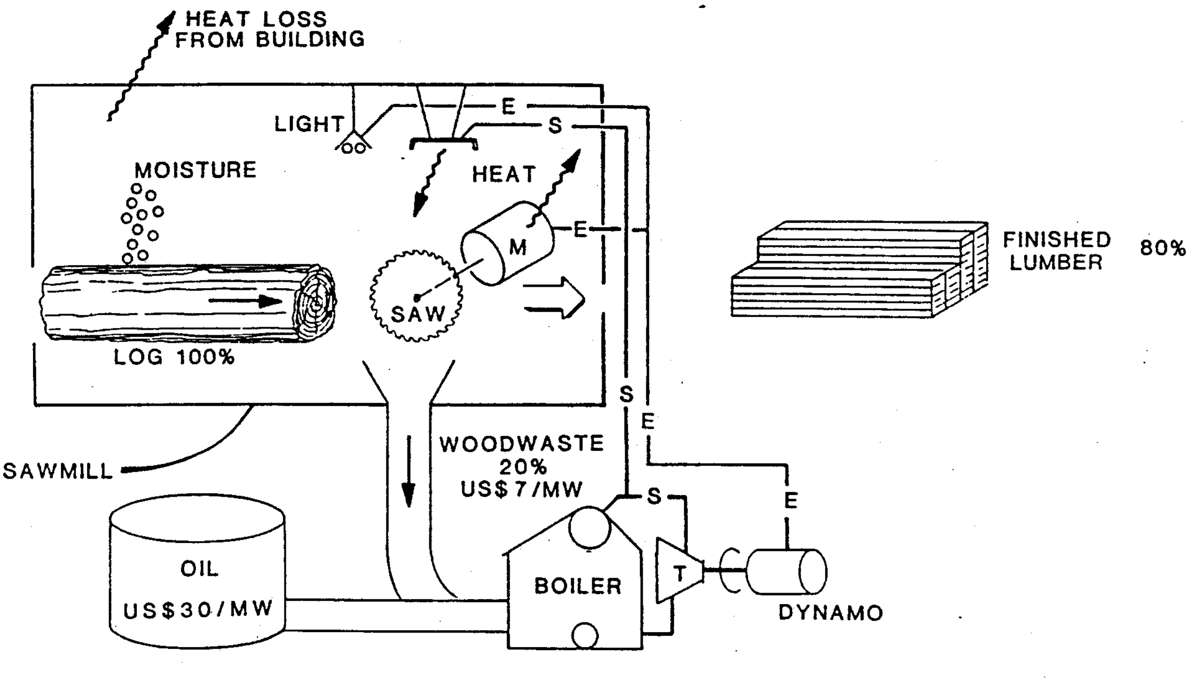


FIGURE 1
EXAMPLE: SAWMILL

REDUCING WOODWASTE TOO MUCH CAN RESULT IN INCREASED PRODUCT COSTS AS MORE OIL IS SUBSTITUTED TO GENERATE LIGHT, HEAT, AND POWER

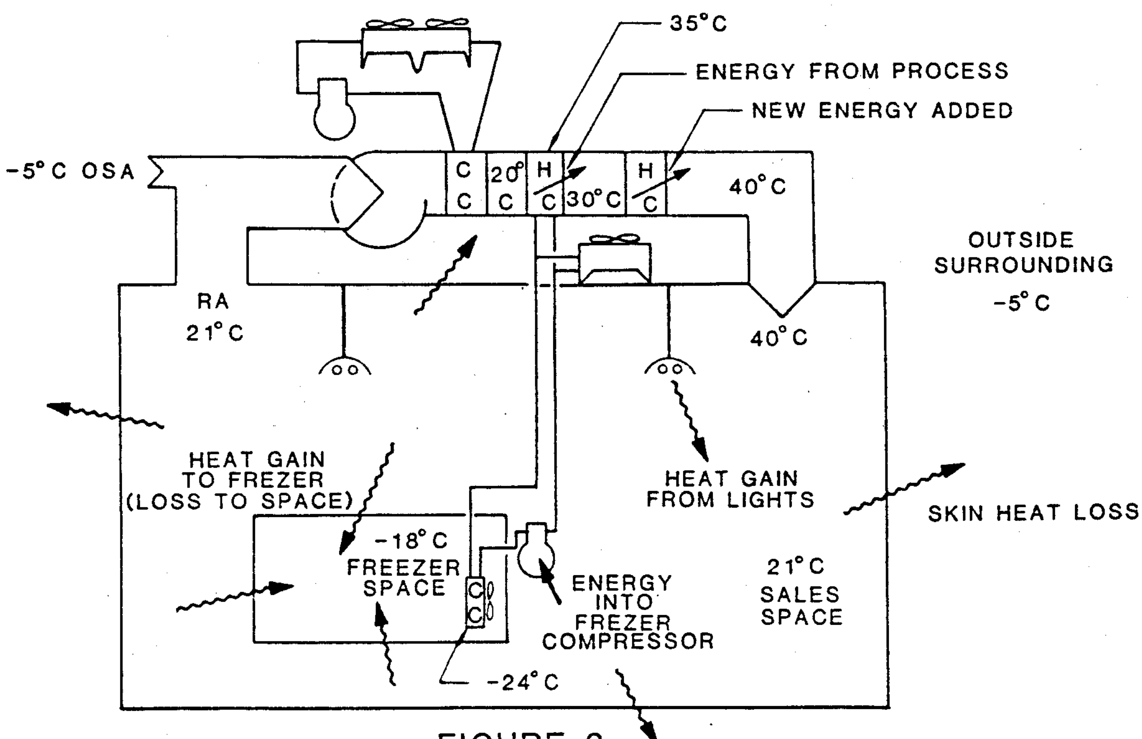


FIGURE 2
EXAMPLE: GROCERY STORE

HEAT ABSORBED IN A FREEZER SPACE IS REJECTED TO MEET BUILDING HEATING NEEDS BEFORE ADDITIONAL HEAT IS ADDED BY CONVENTIONAL HEATING COIL.

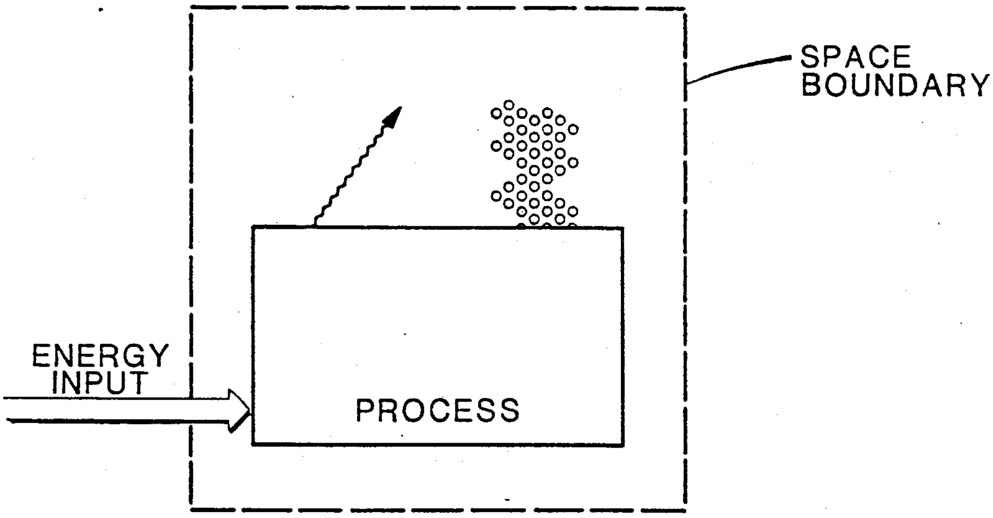


FIGURE 3
CASE 1 HEAT AND MOISTURE ADDED TO SPACE
EXAMPLE: KITCHEN

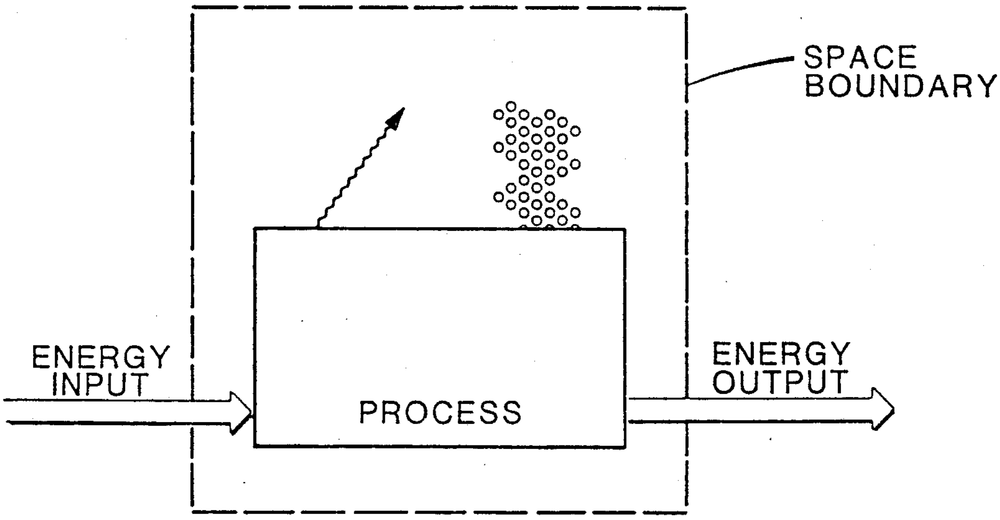


FIGURE 4
CASE 2 HEAT AND MOISTURE ADDED TO SPACE,
1 ENERGY PRODUCT PRODUCED
EXAMPLE: SAWMILL

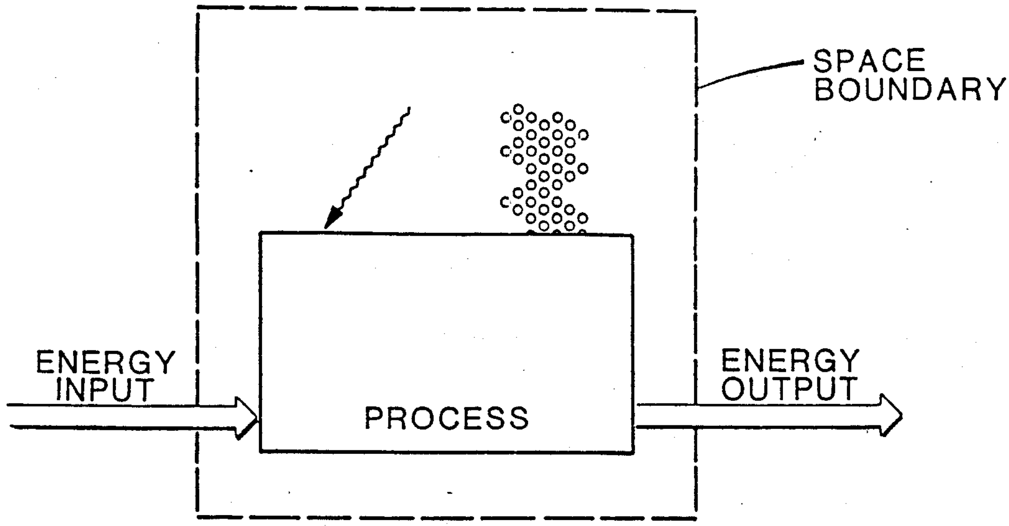


FIGURE 5

CASE 2 PROCESS HEAT EXTRACTION FROM 1 SPACE WITH REJECTION OR RE-USE IN ANOTHER SPACE OR PROCESS

EXAMPLE: PROCESS REFRIGERATION WITH HEAT RECOVERY

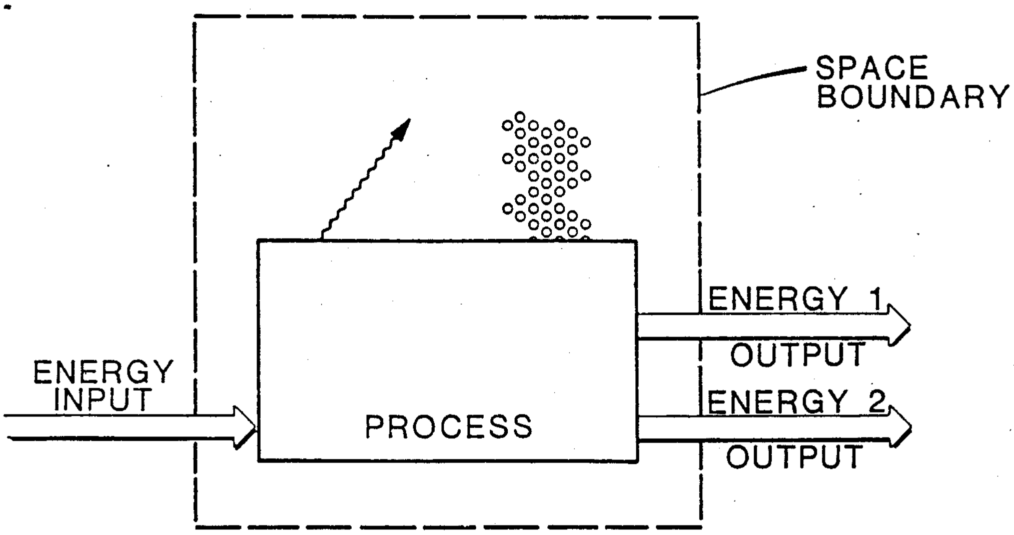
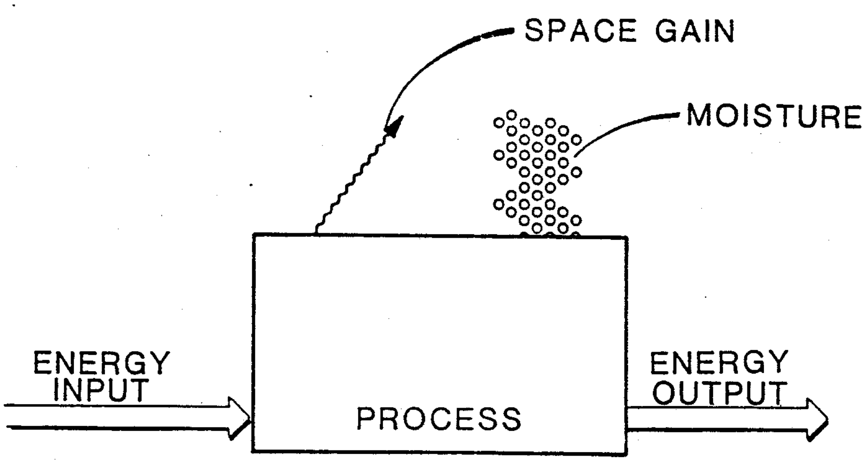


FIGURE 6

CASE 3 HEAT AND MOISTURE ADDED TO SPACE, 2 OR MORE ENERGY PRODUCTS PRODUCED FOR LATER USE

EXAMPLE: PAPER MILL



ENERGY INPUT

FUEL TYPE:

OPERATING PROFILE: I.E. HOURS/DAY, DAYS/WEEK, ETC.

SPACE HEAT GAIN OR LOSS

% OF INPUT ENERGY REJECTED TO OR ABSORBED FROM SPACE

SPACE MOISTURE GAIN OR LOSS

% OF INPUT ENERGY REJECTED TO OR ABSORBED FROM SPACE

ENERGY OUTPUT

EO = f(EI)

FIGURE 7

PROCESS CALCULATIONS

CURVE FITTING ATTRIBUTES:

GENERIC USAGE FOR CASE 1 AND CASE 2 PROCESSES

MINIMAL DATA REQUIREMENTS

READILY UNDERSTANDABLE

MINIMAL DEVELOPMENT COSTS

TRADITIONAL

DETRIMENTS:

NOT RIGOROUS

ONLY VALID WITHIN RANGE OF VALUES ALONG CURVE

MAY MASK IMPORTANT INTERNAL RELATIONSHIPS

FIGURE 8

PROCESS CALCULATIONS

DETAILED CALCULATION MODELS

ATTRIBUTES:

- EXPLICITLY DEFINED FOR A GIVEN PROCESS
- RIGOROUS TIME AND PERSONAL DEVELOPMENT COSTS
- GIVES DETAILED UNDERSTANDING OF PROCESS' ENERGY INPUT
- REQUIRES SUBSTANTIAL PROCESS DATA INPUT

DETRIMENTS:

- EXTENSIVE TIME AND PERSONAL DEVELOPMENT COSTS
- VALID FOR THE PROCESS AS A WHOLE

FIGURE 9