A Note on Process Analysis (Abridged)

Introduction

The aim of this note is to present a simple analytical framework for defining and understanding operating systems. You should keep in mind that the main reasons for understanding an operating system are to allow you as a manager to diagnose problems and develop a reasonable plan of action for the solution of these problems, and to give you the insight to see (and act upon) opportunities for improved performance. You will test this analytical framework on cases after you have read this material. It may be that only after the case analysis will you have a true understanding of some of the terminology and definitions.

You should also remember that our goal is for you to develop your own approach to analyzing operating problems. Thus the procedure described in this note should be modified and expanded to suit your own needs.

Throughout this note you will see the word "process" or the phrase "operating system." Both of these will be used to mean any part of an organization that takes inputs and transforms them into outputs of greater value to the organization than the original inputs. In some cases this definition could include the entire organization. However, in most situations we will focus on a subset of the entire organization that is transforming a set of inputs into useful outputs.

Consider some examples of processes. An automobile assembly plant takes raw materials in the form of parts and components. These materials, along with labor, capital equipment, and energy, are transformed into automobiles. The transformation is called assembly and the output is an automobile. A fast food restaurant takes inputs in the form of unprocessed or semiprocessed agricultural products and energy. To these, labor (the cook) and capital equipment (a stove) are added and the output is a hamburger or other edible food.

Both of the processes mentioned above had products as an output. However, the output of some operating systems is a service. Consider an airline. The inputs are capital equipment in the form of airplanes and ground equipment, labor in the form of flight crews, ground crews, and maintenance crews, and energy in the form of fuel and electricity. These are transformed into a service, namely, a means of transportation between widely separated points. Another process with

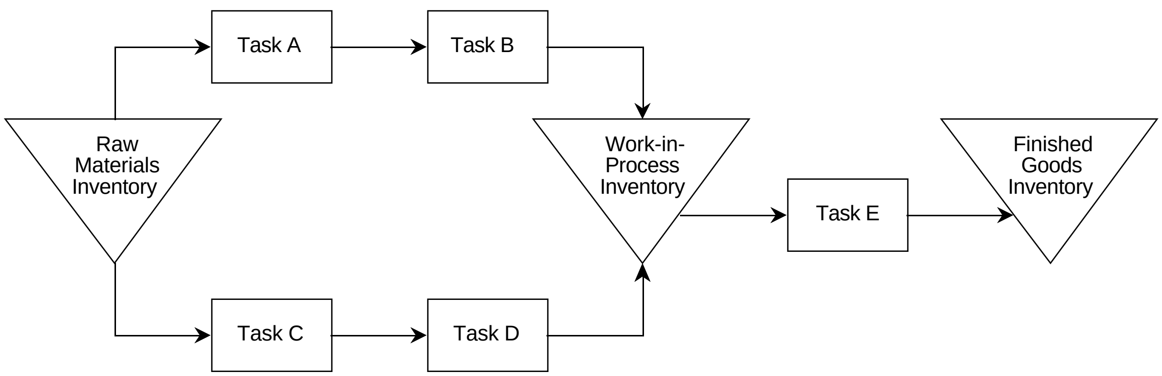
This note is a revision of an earlier note prepared by Associate Professor Paul W. Marshall as the basis for class discussion rather than to illustrate either effective or ineffective handling of an administrative situation.

a service output would be that found in a hospital. Here capital, labor, and energy are applied to another input, the patient, in order to transform this patient into a healthier or more comfortable person.

More formally, a process is a collection of tasks connected by a flow of goods and information that transforms various inputs into useful outputs. A process may have the capability to store both the goods and information during the transformation. In order to analyze a process it is useful to have a simple method of describing the process and some standard definitions for its components. One way to describe an operating system is a *process flow diagram*.

Figure 1 shows the process flow diagram for a hypothetical process. Inputs enter at the left and are converted into useful goods or services that leave the system as outputs at the right. Tasks in the process are shown as small rectangles, flows as arrows, and the storage of goods as inverted triangles. In this hypothetical process some good is being produced. Raw material flows to Task A and Task C from a storage called the Raw Materials Inventory. Task B cannot start until Task A is completed. These two tasks are defined as being in a *series* relationship. You can see that Tasks C and D are also in a series. Task D and Task B are not dependent on each other and as such are defined as *parallel* tasks. Task E cannot be started until all the others are finished; thus a Work-in-Process Inventory is shown before Task E in case Tasks B and D are not completed simultaneously. Task E flows into a Finished Goods Inventory, and from there the output flows out of the process.

Figure 1 Process Flow Diagram for a Hypothetical Process



Once you have been able to describe a process using a process flow diagram you must then analyze its components. After that analysis it should be possible to draw some conclusions about the performance of the process as a whole. In the following sections we will discuss each component and some potential measurement and analysis problems you may encounter.

Inputs

The inputs to a process can be divided into at least four categories: labor, materials, energy, and capital. In order to analyze an operating system, it is necessary to measure these inputs and to determine the amount of each input needed to make some amount of output. Usually we use physical units to measure the inputs – hours for labor and joules for energy, for example. Sometimes, it is more convenient to measure the input in dollars by determining how much it would cost to purchase these units. Thus, in many analyses, it will be necessary to consider the economic conditions that influence the cost of labor, materials, energy, and capital. The problem of measuring the cost of inputs becomes more difficult and requires more care as the time horizon of the problem lengthens.

There are varying degrees of difficulty in determining how much of any input is needed to make a given output. Some inputs, such as direct labor and materials, are fully consumed to produce an output and are thus easy to assign to that unit of output. For example, it is easy to measure how many minutes of labor a barber uses in producing a haircut or how many ounces of beef are used in making a hamburger. Other inputs are utilized in the production of an output, but are not fully consumed – for example, the chef's stove or the barber's chair. The capital input is often the most difficult of the four to assign to a specific output because it is almost impossible to measure how much capital is consumed at any point in time. Generally accepted accounting rules are often used to allocate such fixed costs as capital to each unit of output.

Outputs

The output of a process is either a good or a service. The process flow diagram in **Figure 1** shows a storage before the output leaves the system called a Finished Goods Inventory. In some organizations this Finished Goods Inventory does not exist; the process produces directly for distribution into the environment. In fact, this is an important characteristic of processes that provide a service as their final output because it is often difficult or impossible to store the service for later distribution. In some organizations the finished goods inventory is kept apart from the operating system that produces the good and is managed by a separate group, usually the sales organization.

A meaningful measurement of outputs is often quite difficult to obtain. It is a simple matter to count the number of units produced by some manufacturing organization, or to count the number of patients served by a hospital. It is much more difficult to place a value on this output. The question of valuing the outputs can be approached from an economic point of view if a market will place a value on the output through the pricing mechanism. Thus, if we know the revenue that can be obtained from selling the good or service, this should serve as a measure of its value. For this reason it is necessary to have a good understanding of the economic environment within which the process must exist. "What are the market conditions?" and "What is the competition doing?" are two important questions to address when analyzing a process.

The question of what price will be paid for the output is difficult to answer unless some other information is known about the output. For our purposes three output characteristics will be useful to consider: the *cost* of providing the output, the *quality* of the output, and the *timeliness* of the output. Often none of these measures is easily obtained, but they can serve as a checklist in your analysis of operating systems. It is also quite possible that other characteristics for measuring the output of a process will be useful in some specific situations.

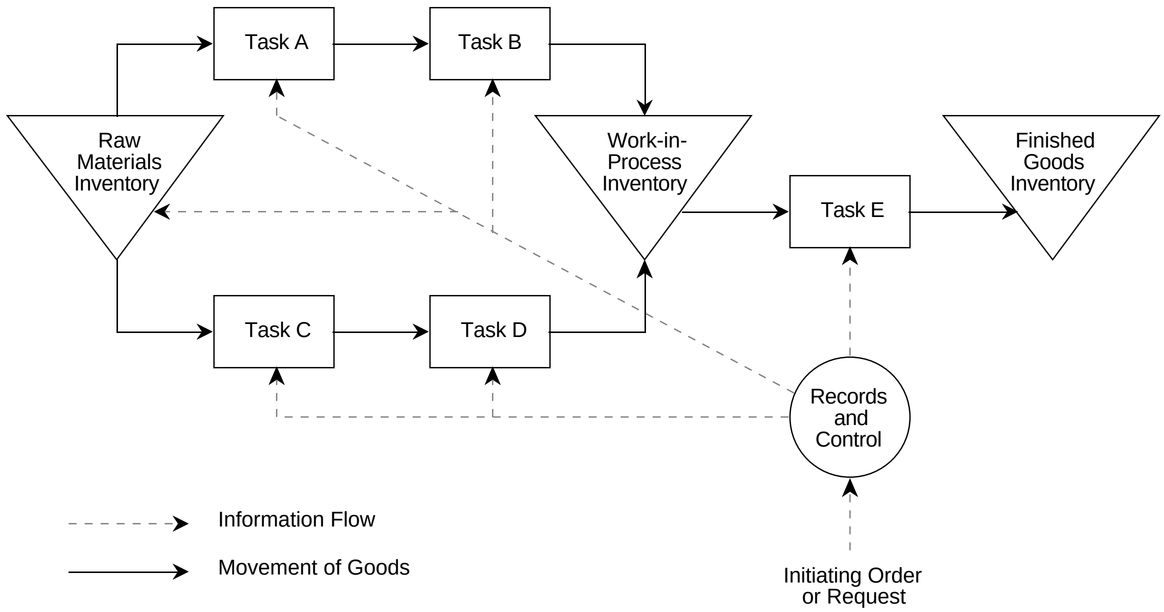
Tasks, Flows, and Storage

So far we have discussed what goes in and what comes out of a process. It is also necessary to understand what goes on inside a process. The specifics of every process are different, but there are three general categories for all activities within the process. These are tasks, flows, and storage.

A task typically involves the addition of some input that makes the product or service more nearly like the desired output. Some examples of tasks are: (1) operating a drill press to change a piece of metal; (2) inspecting a part to make sure it meets some standard; (3) flying an airplane; (4) anesthetizing a patient before an operation. A task quite often takes the form of added labor to the product with or without the use of capital. In cases where some form of automation of the process has occurred, capital and/or material may have been substituted for the labor in a task.

There are two types of flows to be considered in each process: the flow of goods and the flow of information. **Figure 2** depicts our process with the flow of information shown explicitly: the flow of goods is indicated by solid lines and the information flow by broken lines. The first one results when goods are moved from task to task or from some task to storage (or vice versa).

Figure 2 Process Flow Diagram for a Hypothetical Process



Labor or capital is added during such physical flows because it requires workers or equipment to move the goods. The difference between flows and tasks is that flows merely change the position of a good or service in the process while a task usually changes its characteristics. The flow of information initiates and aids in the production of a good or service. This flow results when the necessary records or instructions move from their point of inception or storage to the task, in time to be used in the task. Quite often the information will physically move through the process with the good or service. This happens, for example, when a routing slip[1] is attached to the physical good. In other situations the worker must go to some central location to obtain the information before performing the task, or the worker may carry the necessary information in his or her head. In yet other situations the information arrives by a flow independent of the flow of the good or service being processed. It is often important, in analyzing a process, to consider the information flows in addition to the physical flow of goods or services.

Storage is the last of the three activities within a process we will define. A storage results when no task is being performed and the good or service is not being transported. In **Figure 2** we have shown the storage of goods as inverted triangles. Technically, in many processes there should be an inverted triangle beside every task. If there is no storage between two connected tasks there must be a planned continuous flow between these tasks or the receiving task cannot operate continuously. **Figure 2** shows only one in-process storage.

It is also possible, and in fact necessary, to store information. This storage is shown as a circle in **Figure 2**, with an arrow coming in from the environment to start the process. In this case,

[1] A routing slip describes each task to be performed, where the task is to be performed, and the sequence of these tasks needed to make the output.

there are two kinds of information: records and control. The term *records* typically refers to general instructions, such as blueprints and maintenance documents. The term *control* usually refers to information specific to a given order, such as the due dates and routing procedure for the order, or special instructions that make the order different from the generally accepted procedures explained in the records.

Technology Choice

There are two major areas of the environment that will be useful to consider as you analyze operating systems. We have already explained that the *economic conditions* in the environment are important and that an analysis of them is necessary if you are to determine the costs of the inputs and the value of the output. Second is the *state of technology*; it is more difficult to explain. Technology can be defined as the set of knowledge regarding processes, methods, techniques, and capital goods by which products are made or services rendered. In less precise terms technology is what determines the nature of the tasks and flows within the process and/or how they relate to each other. It is often possible to choose among a number of technologies when designing a process. The choice of process technology will determine the relationship between the tasks and flows and determine the inputs needed to provide the process output. For example, consider two alternatives for providing copies of some information, one using a printing press and the other using a copier. The press requires several tasks to produce the information; typesetting, proofreading, and press operation are some examples. The copier, on the other hand, requires only an operator and an original document containing the information. The cost of providing the information also is different for each technology. The copier has a small cost per copy, but this cost is about the same for each copy regardless of how many are produced. The printing press has a very high setup cost but each additional copy is very cheap. Thus, for large numbers of copies the press has an economic advantage.

As the state of technology changes it may be possible to change the process and achieve the same output with less inputs or to use the same inputs to achieve more output. This will alter the costs of inputs and may improve the quality and timeliness of the output. Changes in technology may allow a process to make entirely new outputs. It is often critical to explicitly consider the state of technology when analyzing a process.

Characteristics of a Process

So far we have defined the process in general terms and given names to various components of the process, namely the *inputs*, the *outputs*, and the *tasks*, *flows*, and *storage* within the process. We have also stated that the process must exist in an environment. The economic conditions will influence the values of inputs and outputs, and the state of technology will influence the nature of the tasks and flows. Using these concepts as a base we can now discuss some process characteristics. We will concentrate on three performance characteristics of a process: *capacity*, *efficiency*, and *flexibility*.

Capacity

Capacity is the rate of output from the process. This characteristic is measured in units of output per unit of time. For example, a steel mill will produce some number of tons of steel per year, or an insurance office will process some number of claims per hour. *Capacity is easy to define and hard to measure*. It is often possible to determine the theoretical maximum capacity of a process – the most output it could generate under ideal conditions over some short period of time. For planning purposes and management decisions it is more useful to know the *effective capacity* of a process. To measure effective capacity it is necessary to know a great deal about the process, and to carefully analyze the particular situation at hand. Quite often managers believe that the capacity of a process is an absolute fixed quantity, like the height of a person. This is rarely true. The capacity of a process can change for many reasons, and we will encounter several cases where this is a key factor. In our example above, for instance, a steel mill may be designed for some ideal capacity. However, this ideal capacity may vary due to such factors as the nature of the raw materials being utilized, the mix of products in the output, and the quantity and nature of the labor input.

Efficiency

Efficiency is a measure that relates the amount or value of the output of the process to the amount or value of the input. The concept of efficiency is widely used to measure physical processes. Every engine has an efficiency and it is expressed as a ratio of output energy to input energy. For example, an engine with 75% efficiency can deliver 75% of the input energy as useful output energy. The energy efficiency of physical systems does not exceed 1.0, i.e., the useful output energy is always less than the input. This is not always true of economic processes. For example, the value of the output should exceed the value of the input if the process is going to generate sufficient resources to support its own continued operation. If we measure the value of output by the revenues it will bring in the market, and if we measure the value of inputs by their costs, the measure of efficiency is profit. Profit, which is simply revenue less cost, is the value of output minus the value of input. Profit is a very simplistic definition of efficiency, and for any real problem the measurement of efficiency may be very complex.

One common measure of efficiency is *utilization*, defined as the ratio of input actually used by the process to create output, to the amount of that input that is available for use. For example, in a labor-intensive process, direct labor utilization is often an efficiency measure of some interest. If 100 workers are employed in a given process, and during an eight-hour shift, 700 hours of labor were consumed in the actual manufacture of product, then the direct labor utilization, during that shift, was 87.5% ([700 hours/(100 X 8 hours)] X 100). In a similar way, to measure capital efficiency, companies often pay a great deal of attention to machine utilization, which measures the percentage of time machinery is actively producing output.

In some analyses it will be difficult to measure the *value* of the output. For example, in some markets it may be possible for a company to initially sell a product of low quality at a standard price. However, over time the reputation of the company may be hurt and other products produced by that company might be less desired by the market. This loss in revenue should have been considered when the decision regarding quality level was made on the original product.

In your analyses you should attempt to take into account long-run effects of the current decision alternatives. When you need to determine the efficiency of the process, you should look at long-run profitability, not just the profit generated from any short-run action.

Flexibility

A third characteristic we often want to consider in analyzing a process is its *flexibility*. This is a measure of how long it would take to change the process so that it could produce a different output, or could use a different set of inputs. *Flexibility* is the characteristic that allows a process to respond to changes in its environment. It is the least precise and hardest to define of all the characteristics we have considered. Often it will be necessary to describe this characteristic in qualitative terms; however, this does not make it any less important to managers.

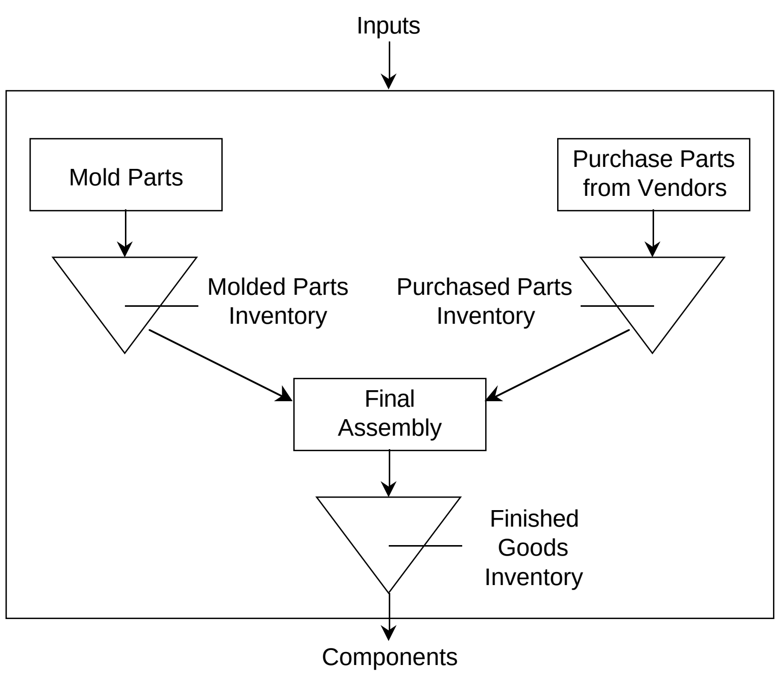
A Simple Example of Process Analysis

The XYZ company supplies a component to several large automobile manufacturers. This component is assembled in a shop by 15 workers working an eight-hour shift on an assembly line that moves at the rate of 150 components per hour. Management believes that they could hire 15 more workers for a second shift if necessary.

Parts for the final assembly come from two sources: the XYZ molding department makes one very critical part and the rest come from outside suppliers. There are eleven machines capable of molding the one part done in-house, but historically one machine is always being maintained or repaired at any given time. Each machine requires a full-time operator. The machines can each produce 25 parts per hour. The workers will work overtime at a 50% increase in their wages. The work force for molding is flexible, and currently only six workers are on this job. Four more are available from a labor pool within the company.

In order to analyze this process it is necessary to describe it. A useful way to do this is to construct a process flow diagram similar to the one in **Figure 3**.

Figure 3 XYZ Component Operation



The tasks are shown as rectangles and the storage for goods (or inventories) as inverted triangles. We often do not know how much is kept in the storage areas, but we can guess that they are not empty. The size of inventory depends on many factors, one of which often is the degree of synchronization of the tasks on either side of this inventory. It may be reasonable to assume that, in order to have uninterrupted final assembly, there will be some molded parts and purchased parts in their respective in-process inventories.

Once the process is described, it is useful to determine its rate of output (in other words, to measure its capacity). It should be obvious that the capacity of the entire process is dependent upon the capacities of the individual tasks. We will assume the task of purchasing parts has virtually unlimited capacity, i.e., it can provide any reasonable number of parts each week. The plastic molding task as currently designed can produce 6,000 parts per week according to the following calculation:

<u>Molding Capacity</u> =

6 machines X 25 parts/hour/machine X 8 hours/day X 5 days/week =

6,000 parts/week

The assembly task is also operating at 6,000 parts/week:

<u>Assembly Capacity</u> =

150 components/hour X 8 hours/day X 5 days/week =

6,000 components/week

Thus, we can conclude that the entire process has a capacity of 6,000 components/week and that the capacity of all tasks are *balanced*.

If XYZ increased to ten machines and ten workers performing the molding task, it could produce 10,000 parts/week. If no change is made in the final assembly task, however, the entire process still only has a capacity of 6,000 components/week *because in the long run the overall capacity cannot exceed the rate of the slowest task*. XYZ could operate its process out of balance if it were willing to build up the inventory of molded parts. XYZ would not want to do this, however, unless it had plans to stop the molding task for some period of time or to eventually increase the capacity of the final assembly task.

Assume XYZ increased its molding capacity to 10,000 parts/week and after some time went to a second shift on assembly. This would increase assembly capacity to 12,000 components/week. Now the overall process capacity would be 12,000 components/week until that inventory of molded parts was exhausted. Then the overall process capability would become 10,000 components/week because the molding machines would be the limiting task. If molding machine operators worked overtime to increase the molding capacity to 12,000 parts/week, the entire process could again be put in balance at an overall capacity of 12,000 components/week, but the cost per unit of output would increase. It should be clear that capacity is not easy to define without stating your assumptions about the availability of inputs, the sequence of tasks, the size of inventories, and many other factors.

One assumption we made implicitly was that only ten molding machines were available. For long-run planning, this is reasonable if the maintenance record is as stated. For a short period of time it might be possible to use all eleven machines and increase the molding capacity. Twenty-four hour operation of all eleven machines would represent the theoretical maximum capacity of the molding task. The effective capacity is less than this maximum amount because of the long-run need to maintain and repair the equipment, even if the machines are scheduled for use 24 hours per day.

So far we have not focused on any decisions that management might make. We have only described the system and placed some limits on its capacity. In order to define some economic alternatives, it is necessary to determine the value of the inputs and the value of the outputs.

Summary

In this example we have only begun our analysis. We have not looked at efficiency or flexibility or any of the several other indicators of process performance that we will explore during the TOM course. Even more striking, we have not tried to address any management problem. In any real case it is clear that the nature of the problem should focus your analysis. Instead, we have tried to show the first two of several steps that might be useful in an analysis. These steps are summarized below.

1. Define the process – determine the tasks and the flows of information and goods. Also, determine where goods are stored in the process. This effort can be recorded in a process flow diagram.

2. Determine the capacity or range of capacities for the process. This will require an analysis of each task and a comparison of how these tasks are balanced. In addition, determine the effect of storage in the system on the capacity of tasks and flows. Inventories may allow the process to operate out of balance for some time, but in the long run the capacity of the process is limited by the capacity of its slowest task.

In many cases you will also need to determine the cost of inputs and relate these costs to the value of the output in some market by comparing the cost, quality, and timeliness of this output to the needs of that market.