First page reads:

JWF MIT
1st draft--10/3/67

(1st class notes?)

Teacher's Manual

Chapter I

Systems

Sample for format of Questions and Responses.

within the loop. In nonlinear systems it is possible for a loop to shift back and forth between being positive feedback and negative feedback.

<u>Question</u>: Rather than using the descriptive treatment in this book, would not a mathematical treatment of feedback systems be more efficient educationally?

<u>Response</u>: One needs to see and understand systems from many different viewpoints. The mathematical viewpoint is but one of the possibilities. In the past the most effective persons in dealing with dynamics of systems have been those trained in the mathematics of feedback systems as taught in various engineering departments. However, very few students come through this particular educational stream and some other approach to system dynamics is clearly required. The mathematical approach itself is not guaranteed to instill the proper perspective because many students see systems only in their mathematical terms and often in the "frequency domain" form and fail to visualize how these systems are behaving in the time domain. It appears that one can start either with the mathematical approach to systems or with the qualitative approach. The choice would depend on the inclinations of the student. We believe that the mathematical treatment could precede, could follow, or could be taught in parallel with the qualitative and descriptive approach. The typical mathematical treatments of systems do not explicitly identify the concepts and principles which are the focus for this course.

Second Class - September 27, 1967

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Fourth Class -- October 4, 1967

In class we discussed the examination questions which students had made up as the day's assignment.

Most of the period was devoted to the second-order loop developed in the previous class.

Even though all but one of the students has studied mathematics through differential equations, none were able to look at the flow diagram and estimate the behavior of the system. Those who were able to see that the feedback loop would oscillate were not aware that it would oscillate at constant amplitude. Those that detected an oscillatory possibility expected that the damping would be a function of the parameter values rather than that the system is undamped and the parameters affect the natural period.

Also, it took a long time to begin to see some of the basic flow and level relationships between the variables. The diagram as drawn with the governing equations on the board clearly shows thatif the past history has been a constant level of procedures and sources, the number of purchase planners must necessarily have been zero. The rate of change of procedures and sources is given in the diagram as proportional to the number of purchase planners.

Likewise, the slopes of the various curves just after time zero could not be determined by inspection (for the equations see class notes for October 11).

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Fifth Class -- October 9, 1967

I asked for opinions on the structure of the Workbook and whether or not the answers should be put into a separate back section away from the questions. The student consensus seemed to be that the present structure of problem Xfollowed by answer is preferred.

I outlined future opportunities for work, research, and teaching in industrial dynamics. I pointed out that Pugh would be starting a mathematics seminar on system behavior next term, and that six or eight students could join that effort, some of whom have already had a feedback system mathematics background and some students who have not. Also I mentioned various reeearch opportunities and that the industrial dynamics courses will all have openings for teachers in the next three or four years.

In a continuing discussion of the second-order purchasing loop which had been developed in the previous two classes, the students began to see that the behavior of the system is XXXXXX unrealistic in terms of an actual managerial system and its anticipated behavior. At this point it was possible to draw the sharp distinction between the real system and the model system and to point out that one is always working back and forth between these two. The model looked satisfactory when first created. One can then stay with the model as it stands until its behavior is thoroughly understood. At that time

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XXXXXXX

the lack of realism in the behavior can lead one back to reevaluate the original description and to formulate a new model which is more satisfactory.

Discussion of Section 2.5

There followed a general discussion of the sales saturation model appearing in book Section 2.5. This revolved around a question from the class about the effect of changing the revenue to sales RS coefficient to a higher value. It took the class some time to sort out the equilibrium relationships which indicate that one would have a larger number of salesmen selling essentially the same product rate. Production would go up very slightly in response to the higher backlog and this according to Figure 2.5b in the text would make a very slight increase in production rate. However, neglecting this as unimportant the predominant effect is a higher sales budget paying more salesmen operating against a lower sales effectiveness and selling the same amount of product.

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Session 6 -- October 11, 1967

This class session started with a discussion of one of the questions raised by a student response to the October 4 assignment to generate a 20-minute class quiz.

<u>The Situation</u>: A stove is burning fuel in a room or house so that it generates heat at a fixed rate in terms of BTU per hour. Is there a feedback loop at work in this situation?

The question to the class was phrased in an effort to make it as broad and comprehensive as possible, yet the majority of students focus on the uncontrolled, constant delivery of heat and say that there is no feedback system. On the other hand some should see that the room temperature does not rise without limit.

Some students will discuss temperature as a possible system level. This gives an opening for a discussion of the nature of a level variable. One generates heat which flows into a system and heat is a proper level variable. However, temperature is merely a consequence of the heat and is given by dividing the amount of heat by the proper thermo coefficient representing the size and nature of the unit receiving the heat. In the equation terminology used in this text, temperature would be an auxiliary variable and neither a level nor a rate variable. One moves heat from one place to another not temperature.

Figure 10/11/67A shows the flow diagram representing the heater and room. The feedback loop does not involve heat generation but does involve the rate of heat loss. Even with this diagram on the board a number of

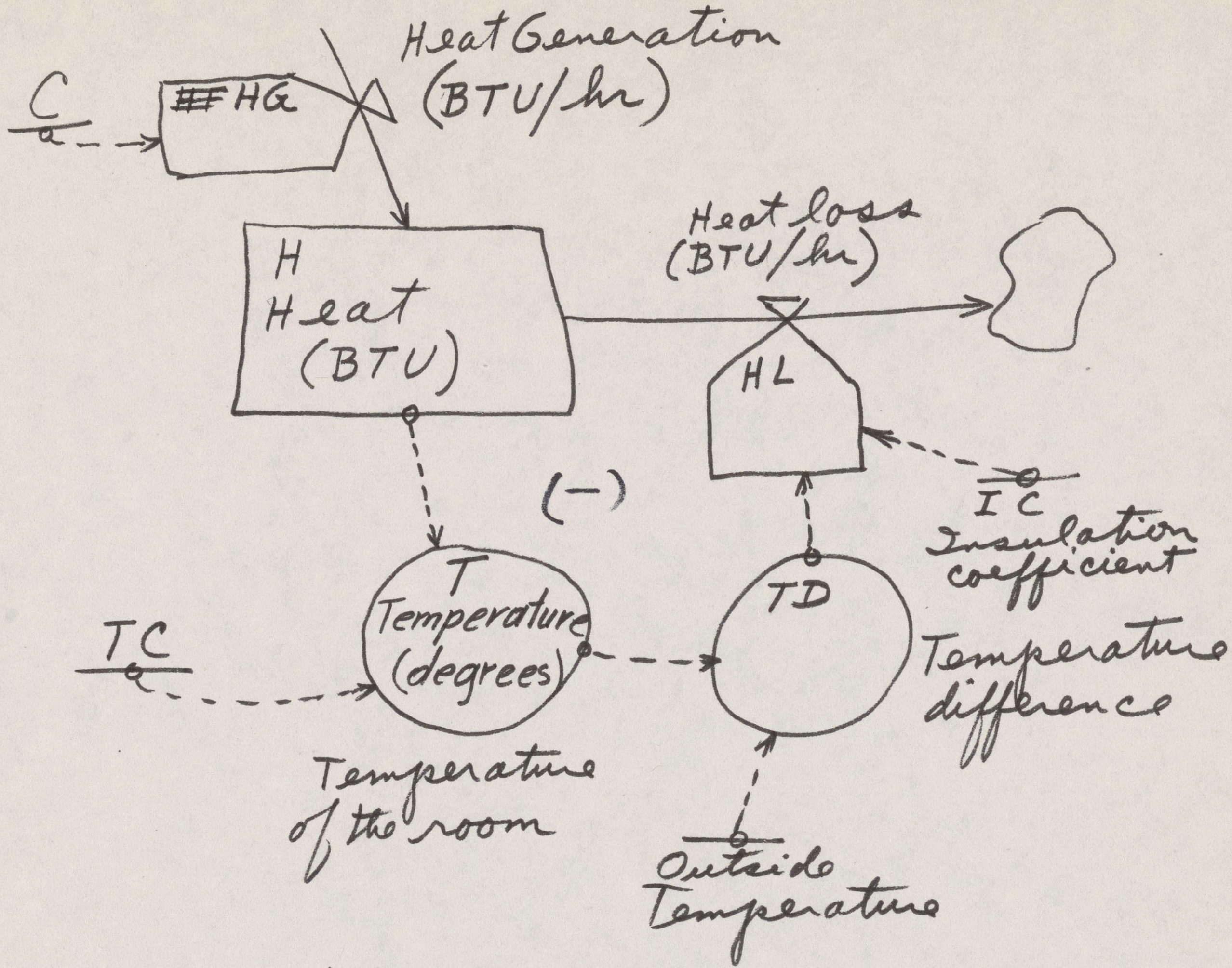

Figure 10/11/67 A

students will not immediately see that it represents a feedback system in which the heat determines the temperature which determines the heat loss which determines the heat in the room.

An instructive discussion can take place in answer to the question asking which of the feedback loops in Chapter 2 of the text most nearly XXXXXX corresponds to this figure for heat flow. Although analogies can be drawn to any of the negative feedback loops it seems clear that the closest representation is the Goods On Order delay in Figure 2.3a. The sub-loop within this larger figure involving Goods on Order and Receiving Rate is a system in which an inflow rate fills the level GO which in turn controls the outflow rate RR. This first-order delay is exactly what is represented in Figure 10/11/67A.

Drawing a figure like this one for heat flow requires that one use concepts and definitions that appear in Chapters that have not yet been assigned (the assigned reading is still in Section 2.5). However, if the instructor is familiar with forthcoming material such a diversion can provide motivation and give meaning to that material when it is encountered. The student at that time will already have experienced the need for such ideas, definitions, standards, and nomenclature.

Discussion of Homework for October 11

In this problem the students were asked to hand compute as necessary to determine the characteristics of the system involving purchase planners and procedures and sources, which had been discussed in earlier sessions. (See the assigned problem attached)

In discussing this home problem several general characteristics of the solutions should be considered.

a. Do the students find a sustained oscillation, an oscillation which dies out, or an oscillation which grows in amplitude?

b. What is the period of the oscillation?

c. One can have the class discuss their general reactions to the problem and what they have observed and what they have learned from it.

If one has in the class students with some mathematical background for problems of this kind they may well have carried out an analytical solution which Xyields the answer which in this text appears in Chapter 10. The period of the oscillation will be

$$\frac{2\pi}{A \cdot B \cdot C}$$

Other students will have gotten approximately the same result by step-by-step computation following the pattern of the examples in Chapter 2.

In selecting parameter values for X A, B, and C, students will in general take values which are too large resulting in reaction XXX times which are quicker than is realistic. Typical periods obtained from student parameters will be six months for an entire cycle of oscillation. This means that the half period of three months is the time required to hire the Xpurchase planners, to have them produce the required procedures and sources, and to XX transfer the purchase planners to other positions. This cycle is probably too XXXX XXXX short by a factor of five. In determining reasonable values we can start by arbitrarily setting the value of C which simply defines what is meant by a procedure and source. Take here a value of C = 1. It might be reasonable to expect that 20 purchase planners could in six months produce the procedures and sources XXXXX necessary for supplying automobile parts at the rate of 1000 automobiles XXX per month. One thousand procedures and sources per XXX 120 men-months gives a value of A = 10.

In determining the value of B we might assume that a discrepancy between target supply rate and the supply capability of 1000 would lead to a hiring rate of 5 men per month. This would give a value of A = .005. These values of A, B, and C of 10, 1, and .005 yield a period of oscillation of approximately 30 months.

The rate equations for the preceding system as given in class had been

$$\text{H.KL} = (\text{B})(1500 - \text{SC.K})$$

$$\text{PSR.KL} = (\text{A})(\text{PP.K})$$

$$\text{SC.K} = (\text{C})(\text{PS.K})$$

Some students will conclude from their computation that the oscillation within the feedback loop for the problem of October 11 diverges. This will be X true because of the added instability introduced by XX the computational XX time interval. For a sufficiently short time interval, say less than 1/10 of the period, the divergence will not be XXXXX extreme. For those who compute without awareness of the importance of the time interval rapid divergence may be encountered. Since the instability due to computation arises out of the relationship between the solution interval and the XXXXX period, some students XX may conclude that instability is a result of changing the parameters of the system when those parameters are given values which shorten the period enough to make the computational instability conspicuous. For vanishingly small XXXXXXXXX solution intervals the oscillation in the system is of continuous amplitude. All finite computational intervals will give some divergence with the divergence increasing very rapidly as the computational interval approaches a tenth of a period.

Students will not have an intuitive feeling for why the loop in the problem of October 11 is undamped. An analogy may help by asking them to compare this loop with a swinging pendulum and to indicate the analogous relationships. Purchase planners becomes the angular velocity, procedures and sources becomes the angular position, PSR is the angular rate, and hiring is the acceleration. This is an exact structural representation of the undamped swinging pendulum. The students may have enough background in physics to be able to discuss how the flow diagram would be modified to represent a pendulum swinging with viscous friction. Under this circumstance there would be a connecting link between X velocity and acceleration such that velocity produces a decelerating force. Without this deceleration the pendulum would continue to swing without reduction in amplitude.

$$\text{Period} = \frac{2\pi}{\sqrt{A \cdot B \cdot C}}$$

$$H.KL = (B)(1500 - SC.K)$$

$$PSR.KL = (A)(PP.K)$$

$$SC.K = (C)(PS.K)$$

Professor Jay W. Forrester
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TEACHER'S MANUAL

Seventh Class - October 16, 1967

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Assignment for next time is to read Chapter 3 and the corresponding Workbook. Also, be prepared to discuss questions 1, 3 and 4 of the problem which was assigned for October 11.

Initial questions related to the computation of dynamic behavior in the October 11 problem. Some had found that the oscillation of the system grows. For this system which in theory sustains any given amplitude of oscillation, a simulation solution will expand some because of the effect of the computational time interval. For very small time intervals (one hundredth of a period) the oscillation will grow very slowly. At And a solution interval of about one-tenth of a period the amplitude of oscillation will increase rather rapidly and still longer solution intervals will be entirely inappropriate.

<u>Question</u>: Does the solution interval relate to the monthly review or the interval between actual managerial decision?

<u>Response</u>: Students usually do not grasp the viewpoint that the solution interval is purely a computational process and bears no relationship to processes within the real system. If delays within the actual system are significant they should be explicitly represented in the model structure. The solution interval should be short enough that it has no influence on the results of interest. No delays or other aspects of the actual system should be hidden in the solution interval.

Question: Why not use an analog computer for simulating system models?

Response: This question almost always arises with groups new to the simulation of social systems. Many of the models we work with are beyond the capability of analog computers. Analog computers have noise and uncertainty which introduces far more difficulty than the solution interval and other considerations in a digital solution. The programming of an analog computer is slower and more difficult than a digital computer equipped with the DYNAMO compiler. Nonlinearities are much easier to handle in the digital computer.

The discussion then turned to Section 2.5 in the book. The remainder of the period was a general discussion touching on many points.

1. A discussion of optimization techniques and how complex systems have multiple maxima and will not yield to maximum rate of ascent techniques.

2. Questions and answers pointing out that the system of Section 2.5 can not be solved analytically.

3. A discussion of how the cost of computation has gone down from $30,000 per million operations in 1945 to perhaps $.30 per million at the present time.

4. In working with a simulation model one is looking for improved solutions to system policy but rarely can show that he has a best operating point.

5. The importance in knowing from a system model the kinds of indicators that the real-life system will contain to identify the XXXXX mode of operation of the system. The rising and then approximately constant delivery delay as seen in Section 2.5 usually indicates XXX inadequate production capacity.

6. A discussion of the inadequacy of information to be found in most actual industrial situations. Financial type of data is usually kept but the other kinds of information are apt not to be recorded.

Professor Jay W. Forrester
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Eighth Class - October 18, 1967

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Discussion of the October 11 home problem. The entire period was devoted to developing reasonable values for the parameters in the system as asked for in Question 1. The students seemed to embark on such a discussion with no evident belief that they can develop reasonable parameters out of their own experience. They are willing to take arbitrary numerical values without thinking of their real-life meaning, but are reluctant to examine the model and the equations to see what these parameter values would mean in a real-life situation.

It took some time for the students to begin to see that the parameter C is entirely arbitrary and is simply part of the definition of what we mean by "procedures and sources." Any value can be taken and it defines procedures and sources in terms of a supply capability. Because it is arbitrary a value of one was taken

(I can't tell whether you changed your mind or whether the belt skipped.)

Many students then expected that other parameters would be equally arbitrary. Another interesting attitude arose in that some students resisted considering values for the parameters because by now they can see that some aspects of the model are going to behave in an unrealistic way. However, it seems good practice and discipline to proceed with the completion of the model selecting values in the most satisfactory way, understand the model as such, and then turn attention to improving the model representation of the reality

For those students who said that the parameter B could be entirely arbitrary I asked if a value of 20 might be taken. They require a long time to discover that given the initial conditions of the system a value of B equals 20 will lead to a hiring rate of managers in the purchasing office of 20,000 men per month. More reasonable figures might be a hiring rate of two men per month based on an expectation that we would build up to some 8 managers who are organizing the purchasing operation. If the initial conditions are to give a hiring rate of two men per month then B equals 0.002.

We then need a value for A. One thousand procedures and sources are to be produced. If 10 men were to do the job in five months which would be a reasonable set of relationships, then A equals 20.

Given the following values

$$A = 20$$

$$B = 0.002$$

$$C = 1$$

then from the prior knowledge of the equation for the period of the system we have

$$\text{Period} = \frac{2\pi}{\sqrt{A,B,C}} = 30 \text{ months}$$

The students might at first find this a surprisingly long time but looking at the first quarter and first half cycles one can see that response can not be much faster.

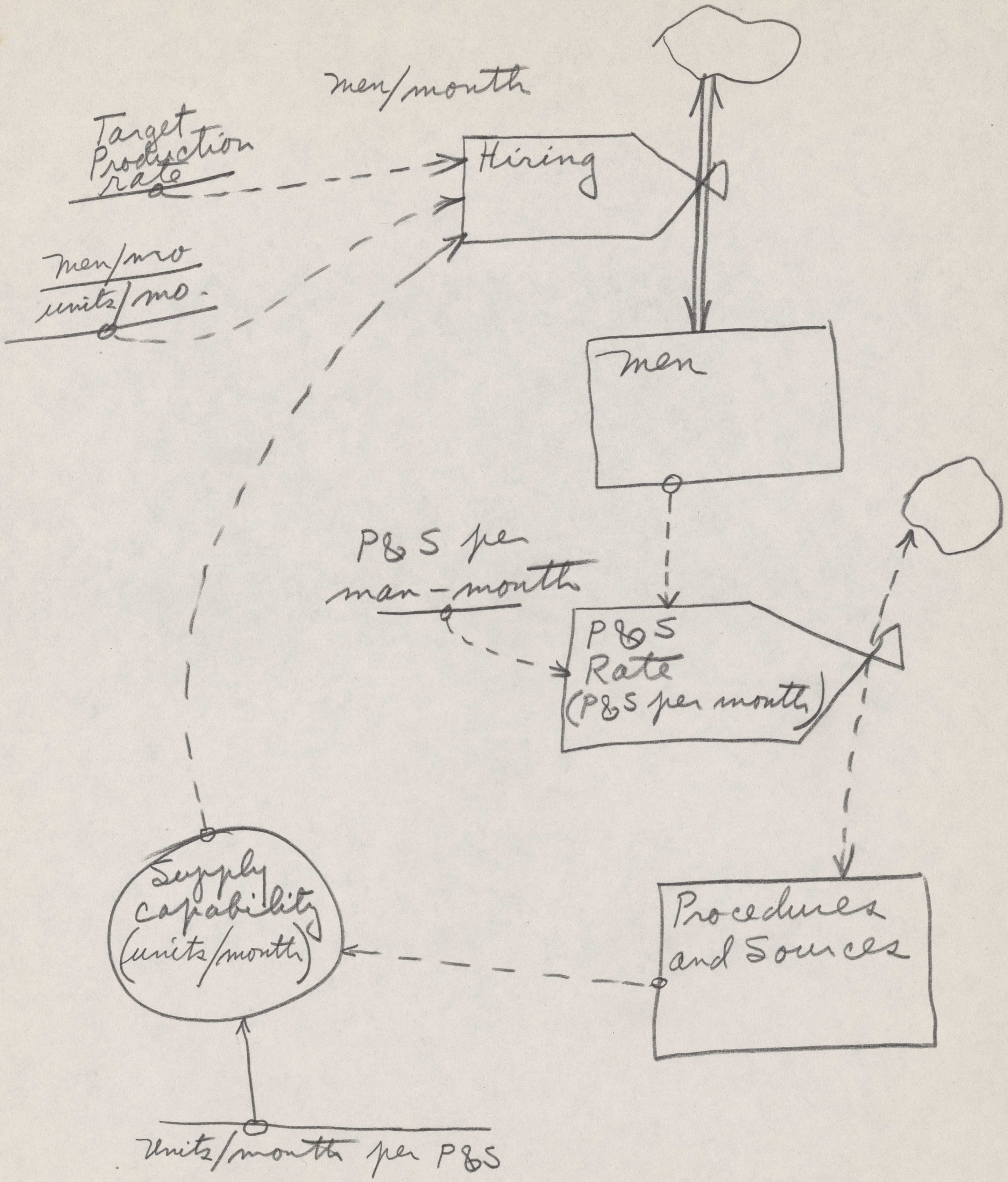

Figure 10/2/67 A

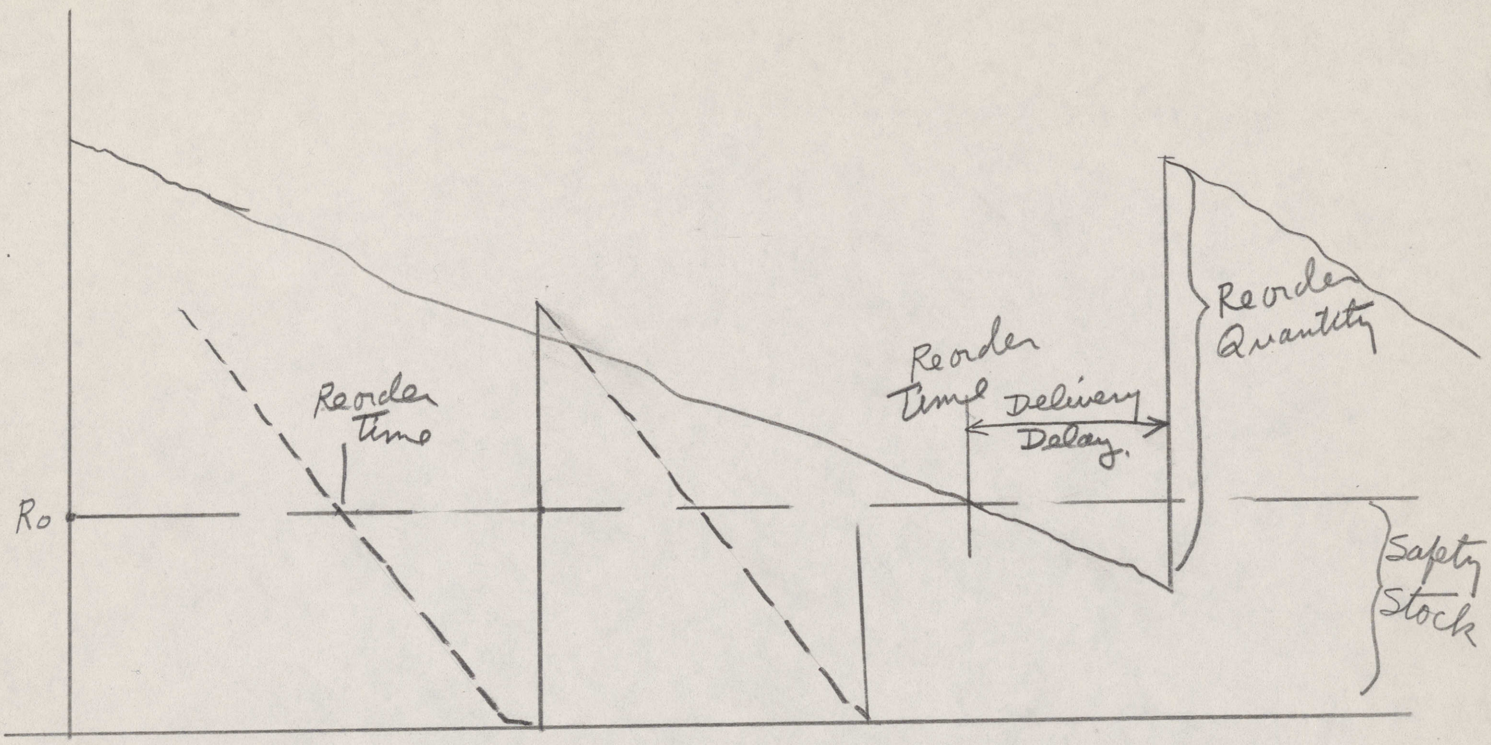

Figure 9/27/67 A