SIMULATION OF PACK FILM MANUFACTURING

by

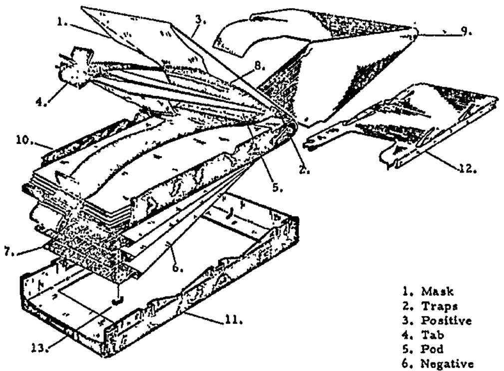
Dr. David Freeman
Professor of Industrial Engineering
Northeastern University
Boston, Massachusetts

Mr. Pasquale Grossi
Industrial Engineer
Polaroid Corporation
Waltham, Massachusetts

Dr. Stewart Hoover
Assistant Professor of Industrial Engineering
Northeastern University
Boston, Massachusetts

Introduction

For many years the Polaroid Corporation had manufactured its familiar film pack. Although this film has been available in both color and black-and-white, manufacture of both types is accomplished in exactly the same manner. Figure 1 is a view of the pack and the components which go into its fabrication.



1. Mask
2. Traps
3. Positive
4. Tab
5. Pod
6. Negative
7. Skirt
8. Leader
9. Safety Cover
10. Pressure Plate
11. Box
12. Box Cover
13. Staple

Fig. 1 EXPLODED VIEW FILM PACK

Recently, a new product now being advertised as "The Square Shooter" was introduced. Planning the production of the film for "The Square Shooter" is the concern of this paper. Except that the parts are smaller, this new film is fabricated in a manner identical to the standard film pack.

Manufacture of this new film posed several questions to the Company. Early in the planning, two major alternatives existed: 1) build a new facility, or 2) integrate production of the new product into the current facility used for the film pack. The first was abandoned as impractical leaving integration into the present facility as the logical step. The simulator to be discussed in this paper was developed to answer questions arising out of the various alternatives for combining production of the two products in a single facility. To understand the problem, a brief description of the manufacturing process is in order.

The pack at the Polaroid Corporation is manufactured in two steps. First the container parts are manufactured, then the film and container assembled. The container consists of three parts, a "box bottom", a "cover", and a "pressure plate" as shown in Figure 1. As each part is manufactured, it is conveyed to a loader which automatically inserts it into a magazine (see Figure 2). The magazine is designed to

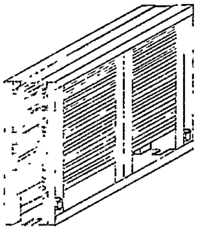


Figure 2 - Magazine

The magazine is designed to accomodate exactly 300 parts. Figure 3 illustrates the loader with magazines in the process of being loaded.

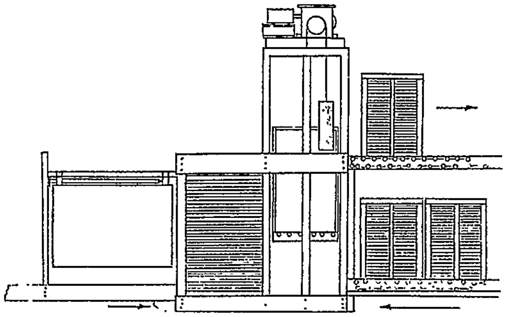
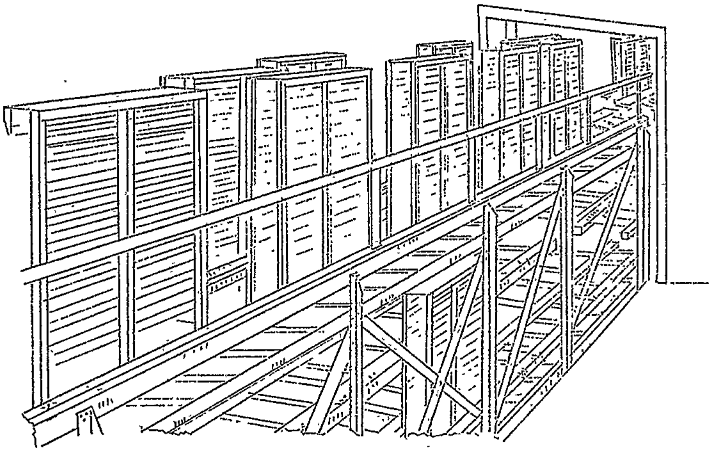


Figure 3 - Loader

When a magazine is full, it attempts to discharge onto a storage conveyor. If the conveyor is full the machine loading the magazine shuts down. From the storage conveyor, additional conveyors lead to an elevator which takes the magazines to the second and third floor of the plant for assembly with the film. The conveyors also serve as temporary storage of magazines thus providing additional buffer inventory. The conveyors are actually two level with full magazines on the top level and empty magazines on the lower level on a return cycle. Figure 4 whows the system in operation. Figure 5 shows a layout of the parts manufacturing area with the conveyor system leading to the elevator. The elevator delivers a load of four sets to one of four assembly areas. A set consists of 3 magazines, one box bottom, one cover and one pressure plate. Each of the assembly areas consists of a network of conveyors two on the second floor and two on the third floor to deliver full magazines and return empties. The conveyors serve as the delivery system as well as space to store magazines as buffer inventory similar to the first floor. the conveyor system again consists of the same two-level system described for floor 1.

FIGURE 4

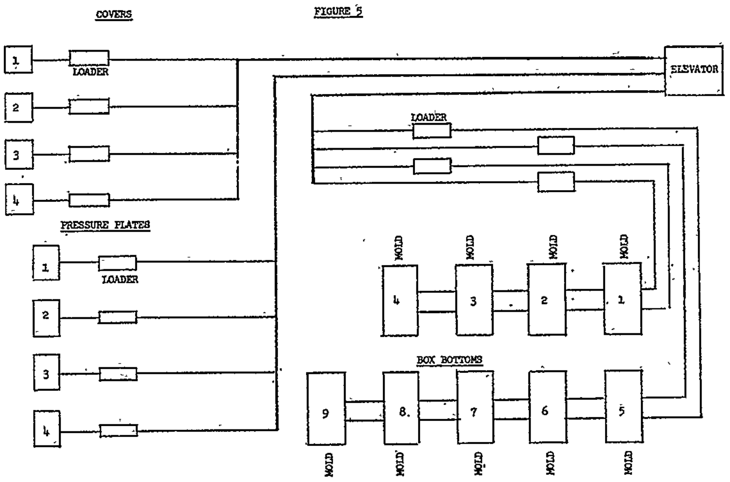
CONVEYORS IN OPERATION



1ST FLOOR

MANUFACTURING AREA

FIGURE 5



Although the layout of each of the assembly areas differs somewhat, Figure 6 is a sufficiently accurate representation of an assembly area on the second floor and Figure 7 represents a third floor layout.

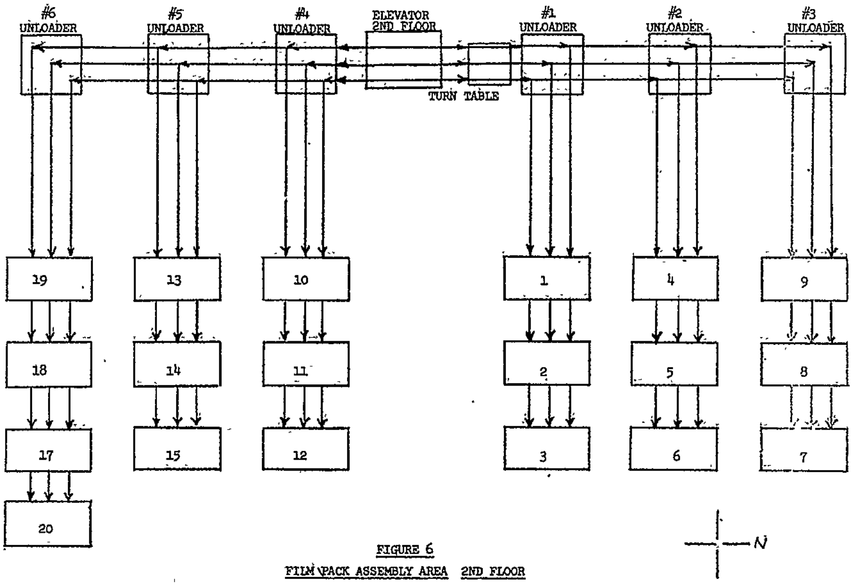


FIGURE 6

FILM PACK ASSEMBLY AREA 2ND FLOOR

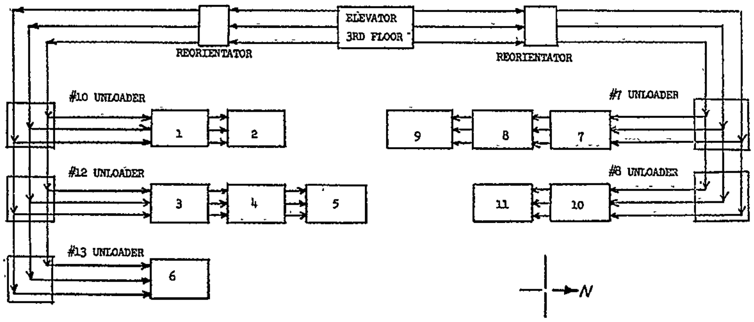


FIGURE 7

FILM PACK ASSEMBLY AREA 3RD FLOOR

The "unloader" shown in Figure 8, delivers the parts as needed to the assembly machines. Each assembly area signals when it needs a delivery of magazines. It will signal a need if there is sufficient space at the assembly area for 4 sets of magazines and 4 sets of empty magazines exist for return to the first floor. If there are four sets of full magazines on the first floor, delivery is made to the calling area. Otherwise the elevator remains on the first floor until a complete load is ready. A delivery will never be made unless an assembly area places a call. Usually more than one area is calling and calls are answered on a first-come-first-serve basis. When the elevator makes a delivery, it removes twelve empty magazines from the assembly area and returns them to the first floor for recycling. All movement on conveyors is automatic.

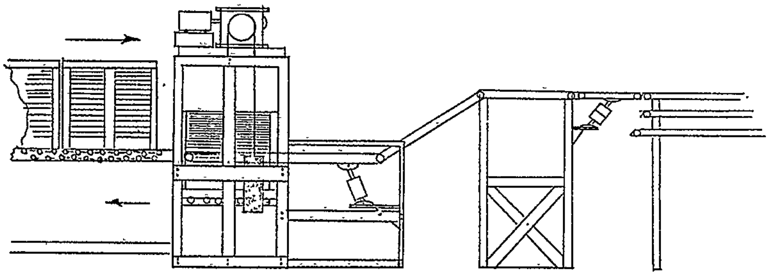


Figure 8 - Unloader

Questions of Major Concern

As long as only one product is running on this system no serious problems arise. However, introduction of a second product into this manufacturing setting raised several questions which had to be answered:

1. Can the existing system or a modification of it deliver magazines to the assembly areas rapidly enough to prevent production losses?

2. With two products being manufactured, how effectively could the existing system or a modification of that system operate without manual override to clear magazines that could block the system?

3. With the introduction of the second product, how many machines on the first floor and which ones should be converted to the new product type?

4. How many magazines should be kept on the first floor and in the assembly areas? Recall that the total number of magazines in an area remains constant since a delivery always consists of 12 full magazines and the removal of 12 empties.

5. In the event of a lengthy failure of the elevator, how long does it take the system to recover? Also, what order of delivery permits recovery with minimum loss of production? This question deserves some elaboration. Recall the elevator is only handling device linking the assembly areas with the first floor manufacturing. Failures lasting as long as one to two hours do occasionally occur. During such an interval all buffer inventories on the assembly floors could easily become exhausted forcing the assembly machines into idleness. All available empty magazines on floor one could be filled forcing machines to shut down. Upon return to operation, the elevator will find all floors in desperate need of parts. This question relates to how best to gain back full production.

The Simulation Model

The entire system outlined in the previous sections was described by a FORTRAN simulation model. It is a combination of event stepping and time stepping. The major event in the overall system is a delivery by the elevator. Thus the simulation focusses on this event. Time is stepped by an increment equal to a complete cycling by the elevator. A cycle always consists of loading 12 magazines on the first floor; travel to a calling assembly area; unloading 12 full magazines and loading 12 empties; return to the first floor; unloading empties into the first floor empty conveyor system. In addition, a cycle may contain some delay caused by elevator failure, delay waiting for full magazines on the first floor and/or delay waiting for a call for magazines from an assembly area.

Once this cycle time is established, two main subprograms are called. The first updates each of the four assembly areas by event stepping through the cycle time. The second sub-program similarly updates all production facilities on the first floor.

The events of concern in these sub-programs are:

A. Assembly Floors and Elevator Events:

1) a delivery to the assembly area

2) a delivery of empty magazines from the assembly area to the elevator

3) a call from one of the assembly areas

4) failure of an assembly machine

5) start-up of a failed assmebly machine

6) assembly machine discharging a set of empty magazines

7) assembly machine accepting a set of full magazines

B. Floor #1 - Parts Manufacturing Events:

1) a machine failing

2) a machine starting up after failure

3) a loader discharging a full magazine

4) a magazine shutting down because the conveyors are full

The programming language used throughout was FORTRAN. Other simulation languages such as GPSS were considered but FORTRAN offered the most flexibility.

Most of the data needed for this simulation was available from historical records. The production department at Polaroid had extensive records on manufacturing rates, yeilds for each part, number of failures per day, etc. What was not available, however was the distribution of the time between failures and the repair time. This particular information was estimated by production personnel.

Model Validation

The validation of the model was quite simple. Since the plant had been producing a single product for many years, the simulator was tested using actual plant conditions. The simulator output closely duplicated the behavior of the plant. Particular attention was paid to the average inventory on the conveyor lines and the average number of empty and full magazines in the assembly areas. The model was duplicating the physical plant quite accurately. It was impossible during the early stages of the project to validate plant behavior for the 2 product case. However, two products are now being produced at the plant and the simulator results agree well with the actual performance of the plant.

This model required about one and one-half man months with two analysts working on the model simultaneously. When the model is run on a CDC 3300 a 15 shift production period can be simulated in less than three minutes of CPU time. The model requires 45 quarter pages of memory.

Experimental Results

The simulator was run to answer questions such as those posed earlier. It continues to be used to provide data for answering questions that arise as the requirements for film output change or as operating conditions change.

To answer the first two questions a modification of the delivery system logic was proposed by the Industrial Engineering Department. Incorporating the characteristics of this modification into the simulation model, a 15 shift simulation of the plant was made and no production losses were experienced for either the original product (product one)or the new product (product two). This demonstrated the feasibility of such a delivery system to respond with minimum manualoverride of the automatic system.

To determine which of the production machines on floor one should be converted to product type 2, several 15 shift simulations were made assigning various machine combinations to the two products. These proved that the last machine on a conveyor line should be assigned to product 2 for maximum performance.

Questions one and two were both concerned with how many magazines were needed and where should these magazines be placed to minimize the possibility of blocking the system.

In one experiment a decision had to be reached concerning how many magazines of product type 1 should be allowed on the main conveyor immediately in front of the elevator on the first floor. A volume mix of approximately 80% product 1 and 20% product 2 was assmumed. It was discovered that 8 magazines was the best number to allow. Allowing a buildup greater than 8 caused situations in which a call for product 2 would be forced to wait too long causing losses on the product 2 assembly. This occurs because if more than 8 exist, at least three deliveries of type 1 product must be made to clear the line prior to release of product 2. The time required was such that inventories were completely exhausted before the delivery of product 2 finally took place. Allowing for fewer than 8 meant that product 1 calls were often too slow in responding since these calls come about 4 times as often as those of product 2 and the time to release magazines and move them into position at the elevator would cause elevator delay. Thus manipulation of magazine configuration led to the fact that 8 magazines (2 elevator loads) was ideal.

Experimentation with different product mixes was used to determine the best configuration given the mix. With equal volume for each product 4 magazines (1 elevator load) yeilds the best overall performance.

Experiments were conducted to determine how many magazines of type 2 should be allowed on floor 1. It was discovered that 13 was ideal. Fewer caused delays at the production machines awaiting a return trip of empties. More than 13 caused the limited storage space for magazines to fill thus forcing the production machine into idleness. For example, 21 magazines forced a blockage within 37 minutes of real time.

Experiments were conducted to determine the best number of magazines to allow on the assembly floors. Unlike the first floor, too many will not cause blocking. However, too few cause losses since not enough buffer inventory exists to take care of the machine until delivery can be made. Although too many will not cause blockages, magazines beyond a certain number do little to reduce the prospect of losses. Thus the high cost of a magazine is not justified. For example, it was discovered that although 55 sets of magazines can exist in a third floor assembly area no more than 20 are needed to assure good performance.

To resolve the question of how to minimize losses given a prolonged failure of the elevator, experiments were conducted forcing the elevator into idleness for 90 minutes. The simulator was programmed to provide frequent output during this 90 minute period and the subsequent recovery period. Observing the behavior of the plant during this period of time provided insight on how the delivery system could be operated to minimize total losses. It was observed that a first-come-first-serve priority for answering calls was not optimum. It proved better to repeatedly deliver to the second floor until a sizeable inventory existed and then start to deliver to the third floor. For example, the first-come-first-serve discipline yeilded large assembly losses and it took approximately 5 hours to fully recover. Giving priority to floor two reduced the losses by more than 25% and reduced the time to recover significantly.

The simulator was used to answer questions beyond those posed earlier. In particular, a question arose concerning the impact on overall performance of a decrease in elevator cycle time. Simulation runs were made with the elevator speed increased by approximately 25%. Although performance was better under all conditions, the above change appreciably improved the capability of the system to recover from prolonged elevator failures. The improvement indicated more than justified the modest cost of physical changes required to achieve these elevator speeds.

Conclusion

The model discussed was used to prove to management that the new product could successfully be integrated into the existing production facility at a minimum cost of conversion. As mentioned earlier, several alternatives existed for modifying the system to accomodate the two products. The one discussed in this paper involved the least capital cost of the alternatives but was believed to be the most risky in terms of potential production losses. Results of the simulator indicated clearly that losses could be held to a minimum with proper operation of the system.

Although precise savings are not available, Polaroid management feels that several hundred thousand dollars of capital investment in equipment modification was avoided and the conversion to product type 2 was made in a minimum amount of time, a very important consideration.

The simulator continues to be used to elevate proposed design changes, changes in product mix and other changes that arise.