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SOFTWARE DESIGN FOR AN  
OPERATING MANAGEMENT INFORMATION AND DECISION SYSTEM  
BASED ON LINEAR PROGRAMMING

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March 1970

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This is a minor revision of a paper presented at the Research Conference on Management Information Systems, Carnegie-Mellon University, June 17 - 19, 1968; and to be published in the proceedings volume. It is based substantially on my Ph.D. dissertation. I am indebted to D.C. Carroll, J.D.C. Little, and L.S. White for their aid.



SOFTWARE DESIGN FOR AN  
OPERATING MANAGEMENT INFORMATION AND DECISION SYSTEM  
BASED ON LINEAR PROGRAMMING

by

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ABSTRACT

While Linear Programming (LP) is acknowledged to be a powerful technique for obtaining optimal production rates, there remains the problem of making an LP model usable as the basis for day-to-day decision-making. This paper describes the design and construction of a support system allowing a group of managers to use an LP model as a decision-making tool. The particular context is meat-packing, but the work is relevant in any situation where an optimization technique is to be used as the basis of a planning and control system involving many controllable variables and a need for timely information.





## Introduction and Overview

The Aggregate Production Scheduling problem may be thought of as the determination of the rates of resource utilization in the production process. This paper attacks the design of an interface between a powerful Aggregate Production Scheduling technique, Linear Programming or LP, and the information and decision system used by a group of managers charged with responsibility for day-to-day resource allocation decisions. The context is the (pseudonymous) Peerless Packing Company where a group of men called provisioners plan and control the rates at which raw materials are bought and allocated to production, by-products are sold, and finished goods are placed into inventory. The provisioners control roughly 1,000 different rates, and LP offers them the potential for a truly global and economic planning model. Moreover, LP by-product information is useful for making decisions about marginal changes in the plan.

The existence of a good technique like LP, or even of an LP model of the Peerless Operations still leaves us short of a useful tool for management. Two problems arise which must be resolved:

First, prices of raw materials change rather rapidly. Like any profit optimization technique, LP is sensitive to price changes. This fact forces us to design our system both to respond quickly when necessary and to produce plans with inherently long life. While this paper considers these points, they are more fully discussed in Sprague (16).



Second, the LP model must be made easy to use, e.g. the reports prepared for the managers must be clear and meaningful, etc. This paper is concerned primarily with this part of the task.

In the following sections we describe the provisioning environment at Peerless and the LP model constructed to aid in planning. We then propose an "ideal" system for making the LP model useful to management. While we believe that the "ideal" system is feasible, given sufficient resources, it could not be built at Peerless. At a second level of consideration, then, is the problem of how much of the "ideal" system could be realized where adequate resources were unavailable. We detail the design and construction of our LP-support system which did indeed preserve most features of the "ideal" system with severely limited resources.

#### The Provisioning Environment at Peerless

Peerless is a pork-oriented meat packer which lost several millions on sales of \$300 million in fiscal 1966. For the purposes of this study, Peerless may be considered to be a pure price-taker\* in both buying and selling, and to have only one plant (located in Cedarton, Iowa), though neither is strictly true. The manufacturing process at Peerless begins with live hogs and ends with several thousand finished products ranging from whole fresh pork loins, through processed meats such as bacon, hams and sausage, to portion-controlled frozen foods.

In order to balance out its production process, Peerless also does

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\*I.e. unable to influence market prices.



substantial trading in primal cuts (major components of hogs, such as green (uncured) hams, green bellies, and loins). For example, Peerless has a considerable consumer franchise for its bacon, so has long been a net buyer of bellies; but it is always selling loins, since it is weak in fresh meat. There are also several components purchased for use in manufacturing, such as cans, cure, and beef for sausage. Similarly, many by-products are sold, including relatively unprocessed items like skin and hair, and highly refined products like lard.

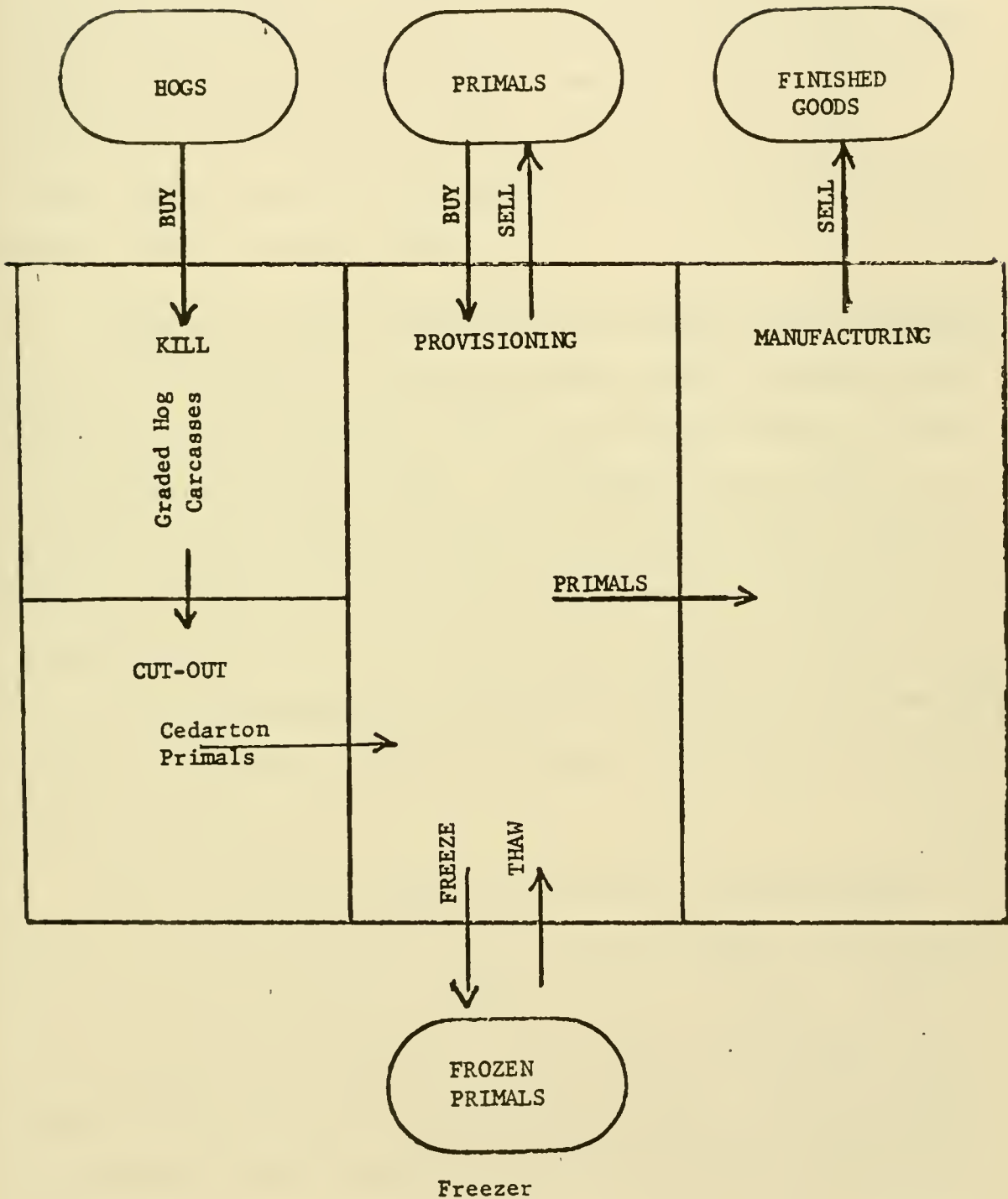
A description of the organization which now solves the aggregate production scheduling problem for Peerless is in order; imbedded within it will be considerable information about the nature of its production process (see Figure I). We should begin at the end of the production lines since this is a convenient aggregation point -- many of the thousands of final products already mentioned differ from one another only in final packaging, and many others are insignificant in volume. There are perhaps 300 unique and important final products.

The production scheduling function for these final products is performed by several men known as product managers. Each product manager serves as the interface between the sales and production operations for one particular category of product. He is responsible for translating a demand figure supplied by sales into a feasible production schedule, and for deciding what priorities should be attached to each individual product when all demand cannot be met. He must also cope with overstocks, old meat, and so on. While he does not have the final say on pricing, he is always consulted before price changes are promulgated and before special marketing efforts are undertaken. When



Figure 1  
GROSS PRODUCT FLOW  
PEERLESS PACKING COMPANY

Open Market







the product manager is dealing with a perishable product such as fresh sausage (bologna, etc.), his life is complicated by short inventories, high spoilage costs, and market demand fluctuations. When he is dealing with a long-lived product like canned ham, he is spared some of the day-to-day fire-fighting. But he must work against long-term forecasts of demand and prices, making the daily decision as to whether or not to put meat into cans, based on his raw material replacement cost which fluctuates hourly.

Each product manager depends for his raw materials on the provisioners, who are responsible for supplying primal cuts to the manufacturing operations. The provisioners' major sources are the internal kill-and-cut operation and the open market. Unfortunately, every primal cut is available in several sizes at different prices and different yields in manufacture. The provisioner cannot control the mix of primals produced internally, but he can control the mix of purchased primals; he has access to freezer space for hedging and filling gaps in availability, and he is responsible for selling any primals not required by the manufacturing operations.

The provisioner has another sensitive duty: he must allocate finite raw material resources among the product managers in those cases where there is not enough of a desirable size to go around. This involves substitution of other sizes, with corresponding changes in expected yields and in the quality of finished product. The provisioner is faced with rapidly varying prices for primals, both in buying and



selling; the quantities available for purchase and wanted by potential buyers also vary daily. Finally, the quality of purchased primals is variable but generally lower than that achieved internally because of the tendency of sellers to cull their excess primals before offering the lower-quality ones to the market.

It is not surprising that provisioners prefer their own product, for which they are dependent on the hog buyer. The hog buyer acquires hogs on the open market for the kill-and-cut operation. He determines how many hogs are to be killed by day and by week. He has considerable flexibility because there are three ways to control the daily rate of kill-and-cut: overtime, extra shifts, and chain speed. He need not work a full week, but Peerless pays each worker in cut-and-kill for 35 hours per week at minimum, so he tries to keep the facilities and men busy.

Hogs are a highly variable commodity and, while prices are quoted on 108 different sizes and grades of hog, each of which tends to cut out differently, the hog buyer has no effective control over the mix of hogs purchased at any time. He is aided by the law of large numbers in that the mix tends to be relatively constant from day to day, changing over the year to reflect stages in the growth cycle.

The hog buyer's most potent decision tool is a daily report showing the profit which would have been earned on every hog killed yesterday if the hogs had been bought at the Chicago market price, killed and cut at exactly standard cost, and immediately sold as primal cuts and offal at the Chicago market price. The usefulness of this tool is ob-



viously limited by the simple fact that Peerless is not primarily in the business of selling primal cuts, and by the fact that nothing is ever done at standard cost, especially when guaranteed wages enter the picture.

Thus, the hog buyer feeds the provisioners, and they feed the product managers. It is clear that the provisioning function is the center of the whole operation. We shall assert that this three-stage decision-making process is a reasonable attempt at coping with the complexity of the manufacturing process and the uncertainty of market prices.

There are about 1,000 important levels to be controlled in the conversion of hogs to money at Peerless, including several hundred within the production process which arise from the many alternative ways in which one single finished product can be created. These make the aggregate production scheduling job entirely too much for one man; but one alternative, decentralized decision-making with local data (Cf the hog buyer), is a priori suboptimal.

In fact, the provisioning function at Peerless is currently handled by several men under the general supervision of the Chief Provisioner whose responsibilities include both "provisioning" and "production." The individual provisioners have individual product-line responsibility and, except for the odd phone call, they operate independently of one another. Once a week, they meet to plan for the following 10-day period. Conflicts are resolved by consultation among the Chief Provisioner and the affected provisioners and/or product managers.



Using Carroll's\* terminology, we may characterize the provisioning system at Peerless as a set of local-real-time systems, tied by a loose communication net, and supervised by a global-periodic system (the weekly meeting). It is doubtful whether any other organization would be more effective. At the risk of sloganeering, we should point out that such an arrangement is modular and open-ended, and that it permits the Chief Provisioner to manage by exception. Unless one wishes to completely overthrow the present system, thereby incurring what are presumably large changeover costs, one must support the local-real-time systems by means of better plans and better tools with which to fight fires, and one must support the global-periodic system with better information. With LP, one can supply the global-periodic system with truly global, truly optimal results.

But the present system permits the provisioners to gather whenever there is a crisis of sufficient size to justify a meeting. The production/provisioning planning system should also be able to help with such ad hoc meetings. Thus, it must be capable of quick response as well as transparent to a variable time between operations of the global-periodic system (meetings).

So far we have considered the needs of the provisioner only in general terms, and this consideration has yielded a very general outline of the system needed to support him. We will now use the term "provisioner" to include the functions performed by the hog buyer and

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\* See (9).





product managers, and we go into more detail about the function of the provisioners.

First, we consider the routine global-periodic provisioning functions:

1. Acquisition: How many hogs should be purchased? On what schedule? In which markets? How many of each of 25 types and sizes of primal cuts should be purchased?
2. Allocation: How much of each primal cut produced, purchased, or removed from the freezer should be allocated to the production of each final product?
3. Disposal: How much of each primal cut should be sold on the open market? At what price? On what schedule? To whom? How much of each primal cut should be frozen for later use?

These decisions are constrained by such factors as cash available, primals available in the market, demand for primals in the market, hogs available, plant capacities, demand for finished product, and so on. They are obviously highly interactive one with another.

Now we consider a sampling of local-real-time provisioning functions:

4. Acquisition: Another packer has offered us a carload of picnics at one cent off market price. Do we accept?
5. Allocation: A sudden order for a large amount of some finished product cannot be filled by present stocks of finished product, in-process product, or even allocated raw materials. Do we acquire more raw materials? Do we acquire more raw materials (primals), substitute another size of the needed primal, refuse the order, or do some combination of these?
6. Disposal: A carload of loins is growing old, but at present market price we take a loss of two cents on each pound. Do we sell at a loss?



7. Price Change: Green hams are up two cents this morning. We suspect that this is a temporary rise which will never be reflected in increased price for finished product. Do we suspend ham processing and/or sell off our green hams?

We now proceed to describe what will be referred to, for want of a better term, the "ideal" system. In so doing we indulge in two fantasies. First we assume that the payoff from the use of this system will justify its running cost. For this purpose we assume that it will consume about 1/8 of the available time on a data-processing system costing \$400,000/year, or \$50,000 in data-processing costs/year. In addition, we allow \$50,000 more for maintenance and special data collection. Routine data-collection costs are assumed to be absorbed elsewhere (as described below). In order to justify its costs then, it must save (or produce) \$100,000/year, or 0.04% of sales. Our second fantasy is to assume that Peerless can support the \$400,000 data processing system mentioned above. This is about 0.16% of sales and is not a priori unreasonable, but it is unreasonable in Peerless' present situation. Nonetheless, we must assume it for now.

Several more assumptions are necessary, all of which are reasonable. First we assume that certain key pieces of data are available at no incremental cost from the accounting system. When this project was begun Peerless was in the process of building and implementing PYRAMIDS (Plant Yield Reporting and Management Information Dissemination System). PYRAMIDS (which at this writing is in regular operation) was to contain all price, inventory, shipment, and yield information as a matter of course, thus eliminating the need for separate routine



data collection. Another assumption is that the role and nature of the men now serving as provisioners will not change substantially.

Finally, we adopt a convention for describing the LP model on which the system is based. The model will be described in terms acceptable to the "bounded variable algorithm"\* in which upper and lower bounds may be attached directly to the columns, primarily because the majority of limitations encountered in formulating this model appropriately affect only a single column. In the few cases where a real inequality row is needed, it costs only one new column to convert it to an equality row with explicit bounds on the newly-created column. This results in a much more compact model (in this case, there would be 2500 or more rows if every bound required a new row), and means that, since every row is a structural equality not subject to the control of management, the important shadow prices -- those for real resources -- are grouped naturally with the remaining information about the columns. Thus the user need not maintain any sort of dictionary to guide him from a particular column to corresponding bound rows. The compactness means that the model can be made to work on a smaller machine than would otherwise be required, though no reduction in solution time is implied. The output is somewhat more compact, since it is unnecessary to present information about the rows. For all these reasons, the model will be built and maintained as if it were in the bounded variable form, even though it may well be run on a machine for which no such code currently exists.

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\* Hadley (3).



Model Description

Before describing the "ideal" system we should discuss the LP model underlying the planning process. The general LP problem, cast into a form consistent with our model formulation is:

$$\text{Maximize } Z = \sum_{j=1}^N C_j X_j$$

Subject to:

$$\sum_{j=1}^N a_{ij} X_j = 0 ; \quad i = 1, M$$

$$L_j \leq X_j \leq U_j ; \quad J = 1, N$$

where  $X_j$  is the value of the  $j^{\text{th}}$  variable or quantity to be determined (e.g., pounds of a primal to be bought);  $C_j$  is the price of variable  $j$ ;  $a_{ij}$  is the coefficient in column  $j$  and row  $i$ ;  $L_j$  is a lower bound for variable  $j$ ;  $U_j$  is an upper bound for variable  $j$ . There are  $N$  variables or columns and  $M$  rows or equations.

An LP solution is feasible when the values of the  $X_j$ 's satisfy all  $M$  equations and fall within their respective bounds. An LP solution is optimal when there exists no feasible change in the values of the  $X_j$ 's which increases the value of  $Z$ . When a solution becomes optimal, each variable has associated with it a level or recommended quantity and a C-range or range over which, cet. par., the price of this variable may vary without loss of optimality. The level and the C-range are the two most important elements of the plan drawn for each variable.





The actual model (see Figure 2) is divided into ten logical units:

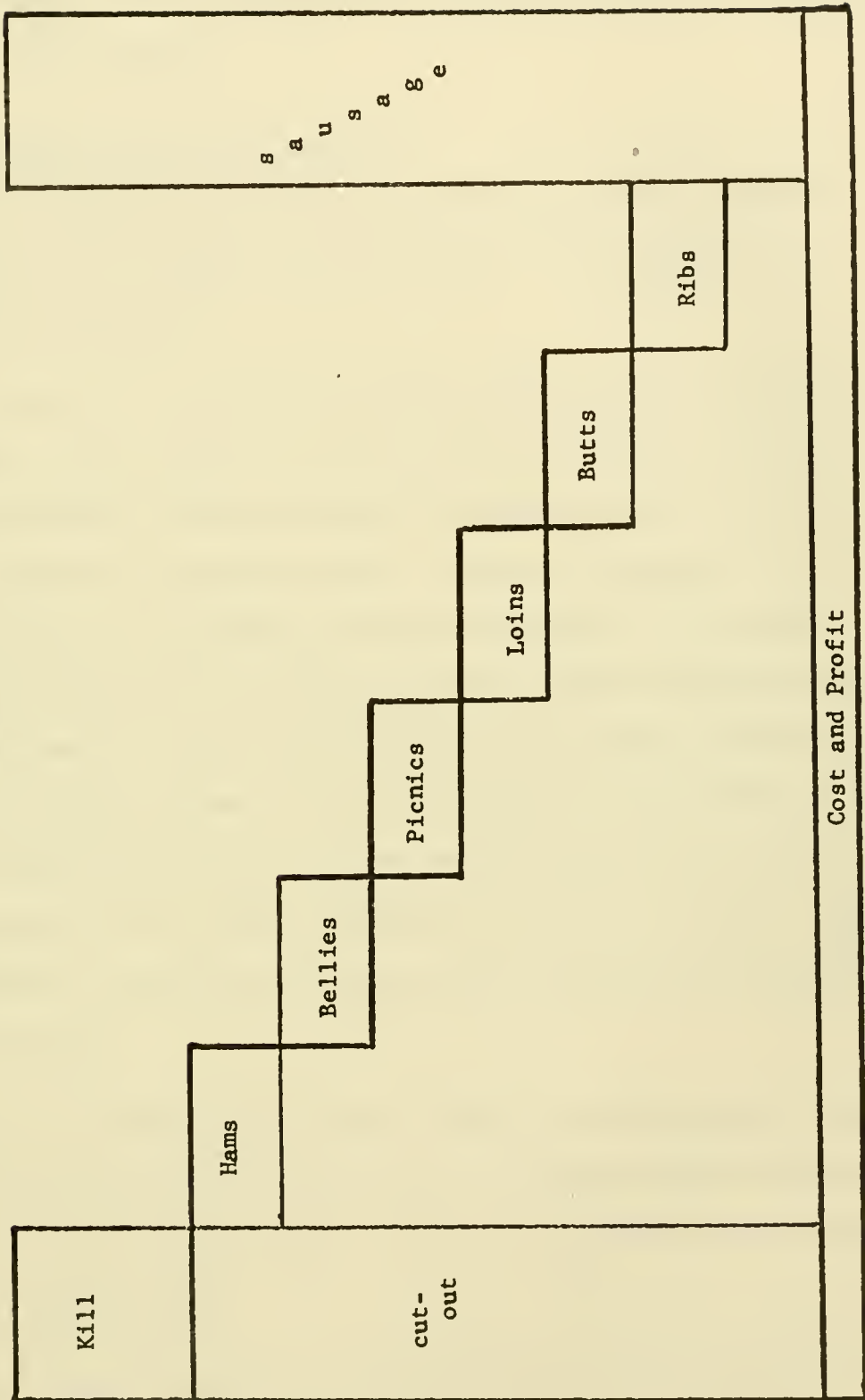
1. Kill: one variable representing total hogs purchased is divided up into 108 quantities of "live weight" of different kinds of hog. The model is also given the opportunity to purchase one pound of each kind of hog separately. This section requires approximately 220 columns and 110 rows.
2. Cut-out: 108 types of hog are converted to 35 types of primal. Labor costs are assessed and by-products accounted for. This section requires approximately 100 columns and 40 rows.
3. Hams: cut-out primal hams are summed with purchased and thawed hams to give total ham availability. This is distributed between sales, freezing, and production. Hams to production are allocated to smoking and/or canning. Each ham is allocated to a particular process ending in one or more finished products. Labor costs and by-products are accounted for. This section requires approximately 300 columns and 170 rows.
4. Bellies
5. Picnics
6. Loins
7. Butts
8. Ribs: These sections are somewhat less complex than hams, but the same general formulations are used. These sections total approximately 300 columns and 160 rows.
9. Sausage: This section serves as a sink for by-products produced in all other sections. Because each material is at least potentially usable in every sausage, each separate kind of sausage requires approximately 50 columns and 10 rows, for a total of 1000 columns and 200 rows.
10. Cost and Profit: This section merely sums up various labor costs and facility usage data for management use. It requires only about 10 extra rows and 10 extra columns.

Figure 2 accurately shows the relationship between these sections; e.g., it is true that hams and bellies interact only at the points of



Figure 2

LP MODEL STRUCTURE





cut-out, sausage, and cost and profit; and it is true that all sections feed the sausage section.

### The Ideal System: General Philosophy

Having described both the provisioning environment and the form of an appropriate LP model, we now describe the "ideal" system and its role as an interface.

One possible requirement of the ideal system is that it dominate the present system. This is relatively easy to accomplish, since it is always possible to invoke the present system for any task which is better accomplished by present methods. However, the power of the present system comes in some part from the fact that the individual provisioners are always in possession of quite recent information about the current status of their product areas. So an obvious requirement on the ideal system is that it supply provisioners with information at least as current as what they now have and, conversely, that they be able to supply it with current information when such would help. Along this dimension, the ideal system looks like an information storage and retrieval system.

Another desirable characteristic is that the system be able to answer such questions as "What would happen if an extra carload of bellies were made available to the plant?" This is the essential characteristic of a simulation system.

And, we want to be able to ask the system for the optimal plan for the following week, based on current or projected information.



In this regard, we are talking about a conventional optimization technique.

Since the Chief Provisioner can call a special meeting to invoke the present system at any time, it is not unreasonable to expect the ideal system to respond as quickly. So the ideal system must consist of data-collection and editing subsystems, an optimization subsystem, and report generation subsystems. It must operate as a true on-line system or at worst as a remote job-entry system with rapid turn-around to provide the requisite level of response time.

The following sections describe the required subsystems. The descriptions are written as if the data-processing system available had massive random-access storage capability and the ability to create and use symbolically-named files. While neither of these features is strictly necessary, both are great conveniences for the system designer. The descriptions also assume a command language which can be used to drive the subsystems. Such command languages are an integral part of modern remote-job-entry oriented operating systems such as OS/360.

#### The Ideal System: Data Generation and Editing

The data-generation and editing subsystems have at least the following capabilities:

1. FORECAST:

Using the PYRAMIDS files of shipment and order data, the system generates forecasts of sales for all finished products for some arbitrary period. It places these forecasts in a file called:





MACHINE . FORECASTS . MMDD

where MMDD is today's date.

2. FCSTUPDATE:

The system delivers the information in the latest file named MACHINE . FORECASTS . MMDD or HUMAN . FORECASTS . MMDD to the user's console or remote printer. It then accepts the user's revisions to these forecasts. It enters the modified forecasts in a file called:

HUMAN . FORECASTS . MMDD

3. MODSTRUCTURE ALPHA BETA

The system accepts changes to the LP structural equations contained in file

ALPHA . STRUCTURE

and places the changed structural equations in file

BETA . STRUCTURE

4. DRAWSTATUS GAMMA DELTA

The system searches the file

GAMMA . STRUCTURE

to find what price and quantity information is required to run the model. It then searches the PYRAMIDS file and the latest version of

HUMAN . FORECASTS . MMDD

to fill in prices and quantities. Some prices will require special manipulation. For example, PYRAMIDS keeps all prices as positive numbers. Some will need to be made negative for the purposes of the LP. In the case of long-life products, some deduction from selling price will be required to account for holding costs until expected sale. For guidance in these operations, the system will refer to file

DELTA . PRICERULES

The result will be a complete LP problem ready to be run in the file



## GAMMA . STATUS

It can be argued that this subsystem permits great generality in model structure (via MODSTRUCTURE) and in price manipulation (via DRAWSTATUS), but that it is slavishly tied to price and quantity information contained in the PYRAMIDS files. This is desirable because the PYRAMIDS files must be correct for proper functioning of the accounting system. However, to correct the occasional error and to allow the user to try out "What would happen if . . ." questions, we also require:

## 5. EDSTATUS GAMMA EPSILON

This permits the user to change the information in GAMMA STATUS, filing the result as EPSILON . STATUS.

The Ideal System: Optimization

The optimization subsystem supports the single command:

OPTIMIZE GAMMA

The system takes the file

GAMMA . STATUS

and converts it into the required input format for the manufacturer's LP package. The LP code then takes over, returning control to the OPTIMIZE command when done. This output is then filed under the name

GAMMA . SOLUTION

It is worthwhile to note here that one would not normally write his own LP package, because many major manufacturers (IBM, CDC, UNIVAC, etc.) supply truly excellent LP codes for their larger machines. Such codes are characterized by large capacity, availability of comprehensive start-up and post-optimality procedures, and, just as important, embody control languages allowing a limited amount of external logic to be performed by the code itself. Thus special procedures in case of in-



feasibility or wildly unlikely solutions can be specified by the user as part of his input.

### The Ideal System: Report Generation

The report generation subsystem has at least the following capabilities:

#### 1. REPORT GAMMA ZETA

Produces for the user a report of the model described in GAMMA . STATUS. For each column of the model (remember that we have no need for row information), the report should confirm:

Alphabetic description of the variable

Objective-Function Coefficient (price)

Lower Bound if any

Upper bound if any

Recommend Level (Solution Value)

Activity Status (in solution or not, at upper/lower bound)



**Maximum Price** (Algebraically maximum value of objective function coefficient at which this column's solution status remains unchanged)

**Activity Limiting Maximum Price**

**Solution Status of Limiting Activity**

**Minimum Price**

**Activity Limiting Minimum Price**

**Solution Status of Limiting Activity**

**Marginal Return for Increase** (Net change in Objective Function for One-Unit Increase in Activity Level)

**Maximum Level** (Before Marginal Return for Increase Will Change)

**Activity Limiting Maximum Level**

**Solution Status of Limiting Activity**

**Marginal Return for Decrease** (Probably has, but may not have, same magnitude and opposite sign as Marginal Return for Increase)

**Minimum Level**

**Activity Limiting Minimum Level**

**Solution Status of Limiting Activity**

This represents most of the information available about a solution short of parametric runs. It suffices to allow the user to:

- a. Base a plan on the recommended levels
- b. Base marginal decisions on the price-and-constraint range information.

In order to prepare this report, the system will have to use both files

and

GAMMA . SOLUTION  
GAMMA . STATUS





For convenience in later use, the complete report should be placed in a file

GAMMA . REPORT

It is likely that the user will wish to suppress some of the output and/or aggregation techniques. In order to allow this, the REPORT command allows the parameter ZETA which, if present, causes the system to build the user's report according to tables stored in file

ZETA . FORMAT

## 2. COMPARE GAMMA OMEGA ZETA

Using the report files from two solutions i.e.

GAMMA . REPORT and

OMEGA . REPORT

the system prepares a difference report according to

ZETA . FORMAT

and presents this to the user.

## 3. PLAN GAMMA IOTA

The system presents file

GAMMA . REPORT or

GAMMA . PLAN

to the user, who enters planned levels and prices wherever his plan differs from the levels and prices in the input file. Whenever he does not enter a new value, the number given in the input file is taken as the planned number. The result is filed under the name



## IOTA . PLAN

## 4. CONTROL IOTA ZETA

The system searches the PYRAMIDS files for actual performance figures (amount produced or allocated, prices realized, etc.).

It then searches

## IOTA . PLAN

for the planned numbers and produces a control report contrasting planned and achieved numbers, according to format file ZETA.

How the Ideal System is Used

Let us suppose that the system is now in use. The current plan is based on files

CURRENT . STATUS  
 CURRENT . SOLUTION  
 CURRENT . REPORT  
 CURRENT . PLAN  
 NORMAL . PRICERULES  
 CURRENT . STRUCTURE  
 NORMAL . FORMAT

and is now a week old. It is time to prepare next week's plan. The sequence

FORECAST  
 FCSTUPDATE

has been run. Slight changes are expected in plant yields due to a change in the average characteristics of hogs available; so, we have to modify the structural equations of the model accordingly. Therefore, we

MODSTRUCTURE CURRENT NEXT  
 DRAWSTATUS NEXT NORMAL  
 OPTIMIZE NEXT  
 REPORT NEXT NORMAL  
 COMPARE CURRENT NEXT NORMAL



Examining the difference report comparing CURRENT and NEXT, we see that several quantities have changed greatly. On further investigation, we see that prices for 2 primals have been reversed in the PYRAMIDS file. We cope by issuing

```
EDSTATUS NEXT NEXT
OPTIMIZE NEXT
REPORT NEXT NORMAL
COMPARE CURRENT NEXT NORMAL
```

This time, our examination convinces us that the model NEXT is satisfactory. We, therefore, hold our weekly planning meeting during (or at the conclusion of) which we issue

```
PLAN NEXT
```

and enter the plan for the week ahead.

From this point on, any product manager or provisioner can find out the current plan and how he is doing in comparison by issuing, say,

```
CONTROL NEXT HAMS
```

where the file

```
HAMS . FORMAT
```

contains instructions to select just the ham sector of the report.

Now suppose the provisioner wants to know whether or not to accept an extra carload of picnics. In most cases, the regular report gives him the marginal value of extra picnics. If he doesn't feel confident about this, however, he can try

```
EDSTATUS NEXT SPECIAL
```

and create a new file

```
SPECIAL . STATUS
```



containing the information that extra picnics are available. He then issues:

```
OPTIMIZE SPECIAL
REPORT SPECIAL NOPAPER
COMPARE SPECIAL NEXT NORMAL
```

where the file

```
NOPAPER . FORMAT
```

suppresses actual production of the regular report, but does allow creation of the necessary file

```
SPECIAL . REPORT
```

He must be aware that the sequence above compares only two recommended solutions, not two plans, but he does get an excellent idea of the consequences of accepting the extra picnics.

The system as described above is thus able to answer virtually all questions of the type posed above. In addition, we need only require that forecast information and realization information (the latter from PYRAMIDS) be converted into weekly rates to make the system absolutely transparent to whether planning is done daily, weekly, monthly, or at any intermediate interval.

The system's response time is, of course, dependent on the speed and size of the machine(s) on which it is resident, and also on its mode of operation (on-line, remote batch, normal batch, etc.); but, in most cases, one day would seem to be an upper bound on a complete re-planning.





On the other hand, such a system would be expensive to build. (How expensive it would be is impossible to estimate at this level of detail in description and without a particular machine and operating system in mind.) Once built, system maintenance would be modest, since the system itself consists mainly of very general data-manipulation subsystems. Maintenance of the data base is largely absorbed by PYRAMIDS. The major flaw in this "ideal" system is that its use would require either some substantial change in the roles of the provisioners or the interposition of a cadre of technicians between them and the system. While neither is strictly desirable, the latter alternative is costly and likely to introduce errors. In the long run, the provisioners probably would find it desirable to become intelligent system users themselves.

There will have to be technicians, of course, to step in when solutions are infeasible, unbounded, or unreasonable. These people should preferably combine computer, LP, and provisioning expertise. Their salaries are part of the cost of running this system.

#### Available Resources

In reality, Peerless had neither the large EDP installation called for, nor the personnel corresponding to such an installation. It will be convenient to organize our description of resources which were available into machine and human categories.

Machines: Peerless had two UNIVAC 1050's, each of which had five tape drives, reader, punch, and printer. While the project was in progress the core storage sizes of these machines were in flux, but



neither was ever larger than 24,576 bytes of storage. Initially, Peerless also had a UNIVAC 1004, which is a general data-conversion machine permitting translation between any valid combinations of cards, magnetic tape, paper tape and printed output. The 1004 was removed when one of the 1050's was augmented by a paper-tape subsystem. In addition, Peerless had card-handling equipment oriented toward UNIVAC 90-column cards, including keypunches, sorters, duplicating punches, and the like.

EDP Personnel: Peerless had an EDP organization consisting of three departments (operations, programming, research) reporting in parallel to the Vice President for Administration; the operations section was the largest. The programming section averaged about six men; the research section was in fact one man. Since both 1050's had been too small to support meaningful use of FORTRAN or COBOL until recently, the programming and operations sections were familiar only with PAL, an assembly-language system.

Non-EDP Personnel: Peerless had a major asset (for building an LP-based planning system) in its Process Design group. The group varied in size (averaging around six) and had responsibility for a wide range of analytic activity (e.g. calculating yields, analyzing hog purchase, etc.). Also, this group regularly ran LP-based sausage formulations. The group had some knowledge of LP and access to the information needed for constructing the LP model, but they were organizationally independent of and isolated from the provisioners, which reduced their effectiveness somewhat.



### How Limited Resources Affect System Design

Preliminary estimates indicated that the LP model underlying the planning model would need about 1500 equality rows and/or upper bounds. While there existed a small-capacity LP package for the 1050's, there was no real hope for installing the LP on one of Peerless' machines. We had to look elsewhere for a machine to run the model.

We planned initially to use a UNIVAC 1107 located in St. Paul, Minnesota, 150 miles from Cedarton. Data transmission at Peerless was to be handled by a high-speed paper-tape system, or by a communication subsystem attached to one of the 1050's. Assuming five-level code, 1500 columns, 1500 rows and/or bounds, and an average of 200 characters of information about each structural variable and bound row, an ordinary 2400 baud telephone line would have permitted transmission of output back to Peerless in less than half an hour. We found, however, that there would be a large expense associated with such a communication subsystem and that the high-speed paper tape device had been removed. The alternative was a teletype 35 ASR for paper-tape punching; this would require about ten hours to punch all the output. Transmission of input to St. Paul was estimated to require another two hours.

It would not have been feasible to accept twelve hours of transmission time per run, especially since the probability of having to make at least two attempts per successful run seemed high. One possible solution was to transmit to St. Paul only changes in input data and to transmit back from St. Paul only changes in solution values, after



stripping out all excess blanks and other unnecessary characters. Preliminary estimates (and later experience with the actual LP model as tested elsewhere) indicated that this would reduce transmission time to about one and one-half hours. This was thought acceptable.

In order to achieve this reduction in transmission time it would have been necessary to maintain data files and file maintenance programs at St. Paul as well as at Cedartron. Starting with a new input file at Cedartron, we would have gone through the following procedure:

At Cedartron:

Using Old Input File and New Input File, produce paper tape containing changes

Transmit change tape to St. Paul

At St. Paul:

Receive change tape

Using change tape and Old Input File, create New Input File

Run LP with New Input File Producing New Output File

Using New Output File and Old Output File, create paper tape containing changes.

Transmit change tape to Cedartron

Rename New files as Old

At Cedartron:

Receive change tape

Using change tape and Old Output File, produce New Output File

Rename New Tapes as Old.





As can be seen, this procedure would have required nearly complete duplication of both information and programs in two widely separated locations. On reflection, therefore, it seemed unattractive. An alternative was carrying tapes to and from St. Paul by air. The time involved for this method would have been about the same as for teletype transmission, but, if necessary, someone could have accompanied the tape, thus allowing a number of possible tries at solution before returning. Planning thus began for a system with basic turn-around time of one full day.

#### Issues Raised by Long Turn-Around Times

The expected one-day turn-around time for the system imposed an absolute requirement that a plan drawn by the system be usable for two days after data input, if re-planning was to occur every day. Prices, however, can change hourly, and this caused some fear that no plan drawn could ever be implemented. Much hangs on our use of the word "usable." Under the present normal system, plans were drawn once a week and real-time modifications made as the week progressed. Certainly, a system which could draw a "better" plan once a week would be "usable" in the context of real-time modifications.

This thinking led to a proposed method of operation: the LP would be run on a basic weekly cycle. The provisioners would meet over the output to make their normal plan for the coming week. During the week of operation, the provisioners would have available the by-product information from the LP as well as a supplementary report detailing plans and achievements, and flagging major deviations. The normal real-time adjustments would be made, but, at some level of discomfort, the entire



planning process could be invoked with one-day lead time, regardless of whether it were early or late in the week.

Previously, we assumed that changeover costs were absorbed in the cost of planning. In fact, we were unable to determine changeover costs for the Peerless manufacturing operation. We were assured that in many cases these were minimal, since machines typically had to be cleaned and set-up each morning anyway. Clearly, however, a large change in the rate of hog-killing would cause costs to be incurred. We decided to leave this to the user of the system by giving him the approximate cost of not following a new plan. He could then decide whether or not to actually change production costs involved. This number also provides feedback to the user as to how necessary re-planning really was.

We expected that initial use of the planning system would show re-planning much more often than once a week, but that the proportion of times when new plans were implemented on the production floor would be relatively low. We also expected that, as users became more familiar with the system, their demands for re-planning would fall, while the proportion of implementation would rise. These expectations were based on the belief that humans are efficient pattern-recognizers and on the belief that profound changes in the structure of a solution would have relatively small effects on the value of the solution.



### Design and Construction of the LP Support System

The LP support system was designed to give the users as many features of the "ideal" system as could be achieved on a small tape-oriented computer, given the necessity of carrying tapes back and forth between the "home" computer and the large machine required for the LP. Three major features had to be sacrificed entirely, though partial compensation was possible. (Other features, recognized as worthy but not absolutely essential for operation, were deferred and, as a result, never implemented.) The three lost features were:

- 1) On-line editing and modification of coefficients;
- 2) On-line calls for special reports; and
- 3) Monitoring by partial solution.

In our view, the most serious loss was the third. All question as to whether or not a solution remains optimal in the face of multiple price changes becomes unimportant if the LP code itself is available for monitoring. The process is simplicity itself: using the old basis inverse and the new set of prices, perform one matrix multiplication to determine the new set of reduced costs. If these are all non-positive (except for variables at upper bound which must be non-negative) then the solution remains optimal. Since the basis inverse really specifies a set of row transformations sufficient to change the initial simplex tableau into the final (optimal) tableau, it matters very little whether the inverse is kept in terms of the actual inverse (around 400,000 numbers), product form (usually many fewer numbers), or just as a list of variables and their solution status together with



The original tableau (least of all because of the sparseness of the original matrix). In any of these cases, the time required to recalculate the reduced costs is on the order of a minute or two on the class of machine needed to support the LP code itself. However, on a UNIVAC 1050 with 24K core and no random-access mass storage, this task becomes huge.

In this section we describe the design of the system in broad terms. It is appropriate to begin with the most important artifact of the system.

The LP Master File: The LP Master File is a single reel of tape containing all information required to run and/or interpret two different versions of the model. We will call these two models the current or A-model and the new or B-model. Both models are on the same tape for reasons of simple data-handling ease. The file is in column order, and for each column contains:

Column Coefficients for A-model  
 Alphabetic description of column  
 Solution information for this column of A-model  
 Column coefficients for B-model  
 Alphabetic description of column  
 Solution information for this column of B-model

Let us consider the use of the Master File throughout the planning cycle. Suppose we have just implemented a plan based on the most recent solution of the LP. At this point (take it on faith) the A-model and the B-model are identical. We now consider functions of the

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\*See the Appendix for samples of many system artifacts.





support system, given this initial situation.

Modify Prices and/or Bounds: A new set of prices and bounds are prepared and punched on cards. These cards are used to update the coefficients and solution information corresponding to the most recent run of the LP, while the B-sector contains coefficients for the next run of the LP. B-model solution information is now meaningless.

Modify Model Structure: The same as above, except that coefficients other than prices and bounds may be changed, and whole columns and/or rows may be added or deleted. These two functions, which are handled by the same program, are the equivalent of MODSTRUCTURE (and EDSTATUS).

Monitor Changes: A report is drawn showing the net difference between the coefficients in the A-model and the B-model. That is, every coefficient which is either:

Different in B from value in A; or  
Present in B but not in A; or  
Not present in B but present in A

is written out in a report giving before-and-after values.

Monitor Prices: Every column whose B-price is outside its C-range as defined by the A-solution is noted on a report, together with full information from both models.

List Model: The complete B-model is listed in column and/or row order.



Draw Input Tape: The B-model is transformed into a tape suitable for use as input to the LP package.

Optimize: Not a part of the support system, this step consists of carrying the LP input tape as prepared above, the optimal basis (on cards) from the last run, and any changes deemed necessary by the user, to the machine on which the LP code is resident. The output is a new optimal basis deck, an LP output tape, and printed reports.

Update B-Solution: The LP output tape is used to update the B-solution in the Master File. The Master File now contains the most recently implemented model (A-model) and the most recently unimplemented model (B-model). Solution information for each model corresponds to its coefficient information and includes the quantities called for previously.

Report: The entire B-solution, together with alphabetic descriptions, is written in a report suitable for use by the provisioners and product managers.

Report Solution Changes: The entire Master File is scanned, and whenever the B-solution differs in any way from the A-solution, both are written out. By means of this function, the user can judge how profound the changes in solution actually were. In addition, this report contains the three objective function values mentioned above, namely:

A-model objective function;  
B-model Objective function; and  
A-B objective function (A-quantities at B-prices)



Accept Solution: This routine (actually the same as the Report Solution Changes routine) produces a new Master File whose A-section has been replaced by the B-section; that is, the B-model is declared to be current.

Dump Model: The entire B-section, including coefficients, descriptions, and solution information is dumped in a single report to the major user. This gives him a superior ability to trace out any unusual result. In fact, this is the same routine which is used to create a listing of the model in column order. The difference is in the timing; the column list comes before the solution, the dump afterwards.

This completes the description of the main parts of the LP support system. In addition, there are two routines designed to prevent errors.

Monitor Inconsistencies: Every alphabetic description begins with a single character giving the class of variable (e.g. B for buy, S for sell, A for allocate, etc.). This routine checks every column description against its new (B-model) price and flags inconsistencies such as a positive price for a bought quantity.

Manipulate Prices: Designed to prevent errors by reducing the task of data input, this routine accepts a table of relationships between one master price (say the Chicago market for a primal) and many dependent prices (cost of purchase, return from sale of the same primal at Cedarton). It then accepts master prices and punches change cards to correspond.



Implementation of Variable Planning Interval Through Human

Decisions: There are obviously two decision points in the replanning process. The first comes in deciding whether or not to re-plan. This decision is made by the provisioners using certain system functions already described. Remember that the B-model has the cumulative changes in coefficients since the A-model was run. At any time, the provisioners can invoke the Monitor Prices routine to get a list of all columns whose prices fall outside their C-ranges. The provisioners must still decide whether or not to re-plan. They will be aided by the report from the Monitor Changes routine. For instance, if there are a large number of columns appearing on the Monitor Prices report, but the Monitor Changes report shows them all to be proportional changes in the prices of various versions of one single primal, the odds are good that the current solution in fact remains optimal.

It is also true that, at any time, the provisioners can invoke the Draw Input Tape routine to initiate the remote procedure for obtaining an LP solution. Having done so, and having obtained an LP Output Tape and run Update B-solution, the provisioner is forced with deciding whether or not to accept (implement) the new solution. To aid in this procedure, he has three documents: the LP report as produced by the LP code itself; the LP report produced by the Report routine; and the Change report produced by the Report Solution Changes routine. He must judge whether the return from changeover to the new plan justifies its costs. These reports, and (later on) his experience in previous decisions of the same sort, should allow him to make good decisions on the question of acceptance.





Construction of the System: The system was constructed as a set of modules, some of which were programmed by UNIVAC personnel, the rest by Peerless. (See Figure 3.) The major modules were:

1) Create sorted change tape. Cards are accepted in a variety of formats, converted to a single consistent format, and sorted into column-row order for updating the Master File. One problem arose here -- the sort, a standard merge procedure, would not necessarily preserve the order of tied entries. As a result, no duplicate column-row combination could be tolerated in a single batch of change cards. This meant that change cards from two separate days (or, for that matter, hours) could not be batched together. A normal procedure for pulling duplicates was instituted temporarily, but the long-term solution was to append the serial position of each card in a batch to the sort key before sorting.

2) Update B-model. A sorted change tape is passed against a Master File, and a new Master File created whose B-model embodies the changes specified. As above, no duplicate changes were tolerated in the first version; later versions were to ignore all but the last such duplicate.

3) Extract Extended Master File. The Extended Master File, consisting of complete B-model information in an easy-to-process form, is extracted from the Master File. This is used by several other modules (see below), and, as a bonus, is in the same format as a sorted change tape, so that it can be used to create a whole new B-model if necessary.



Figure 3

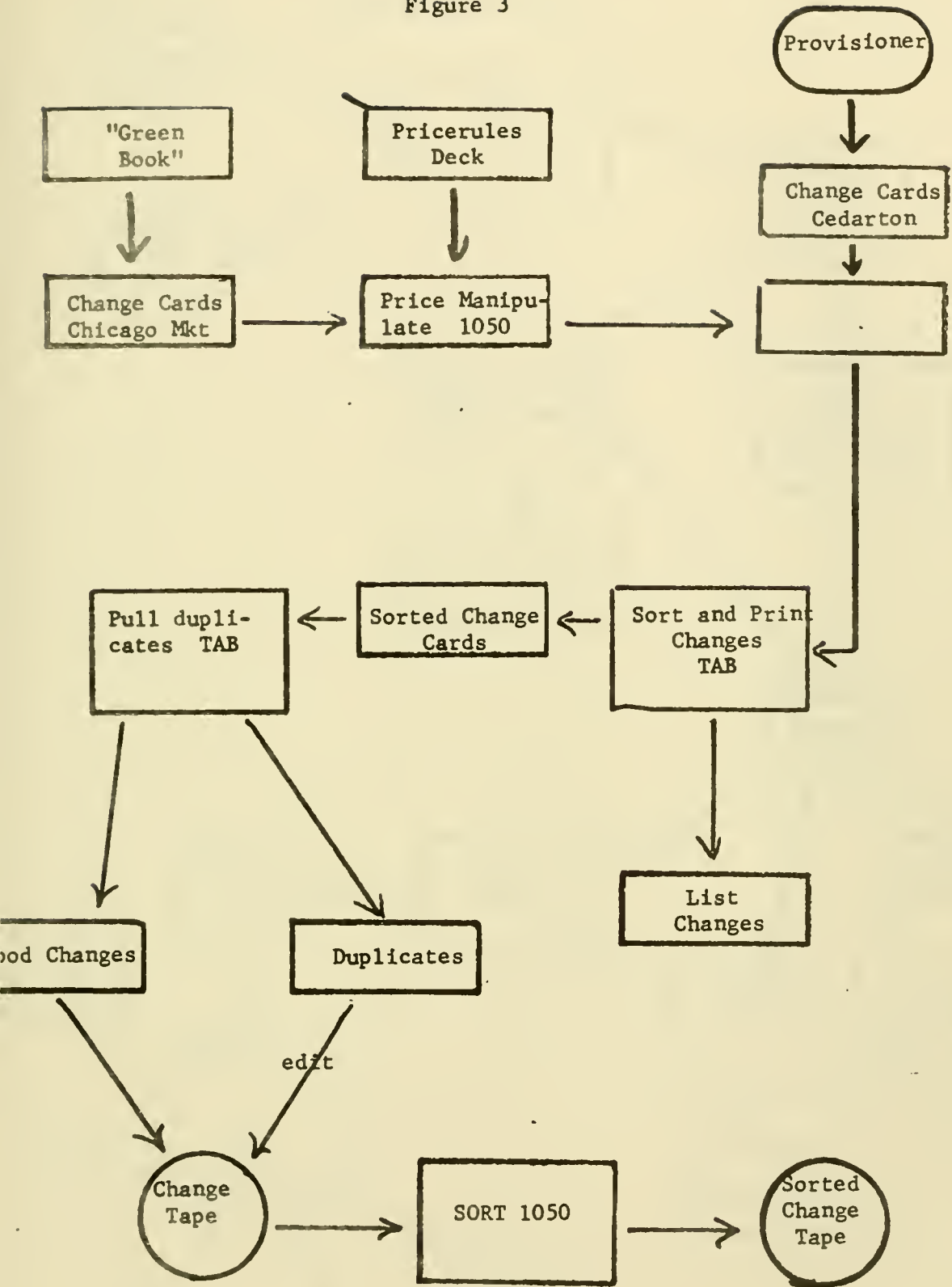




Figure 3 (continued)

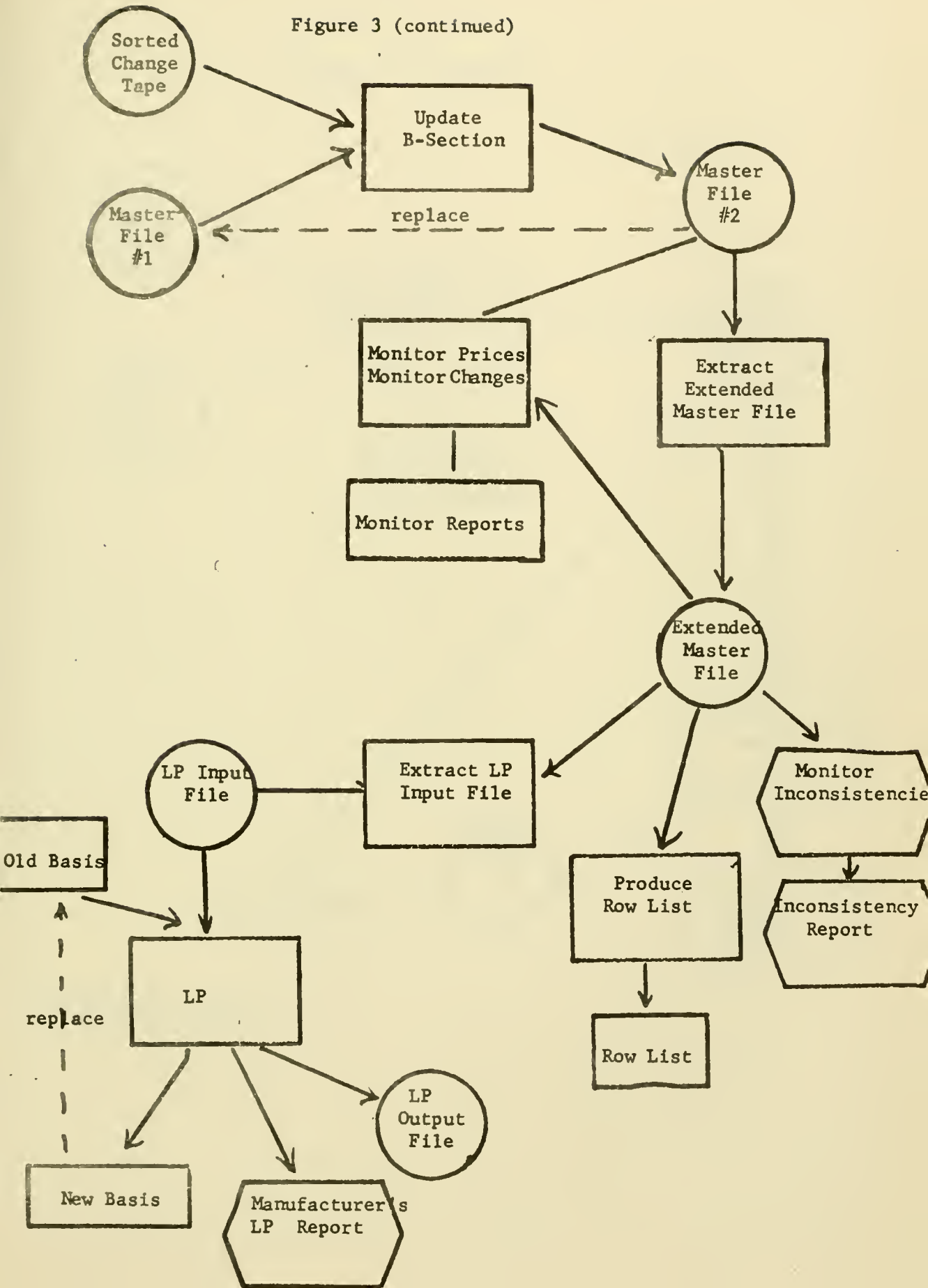
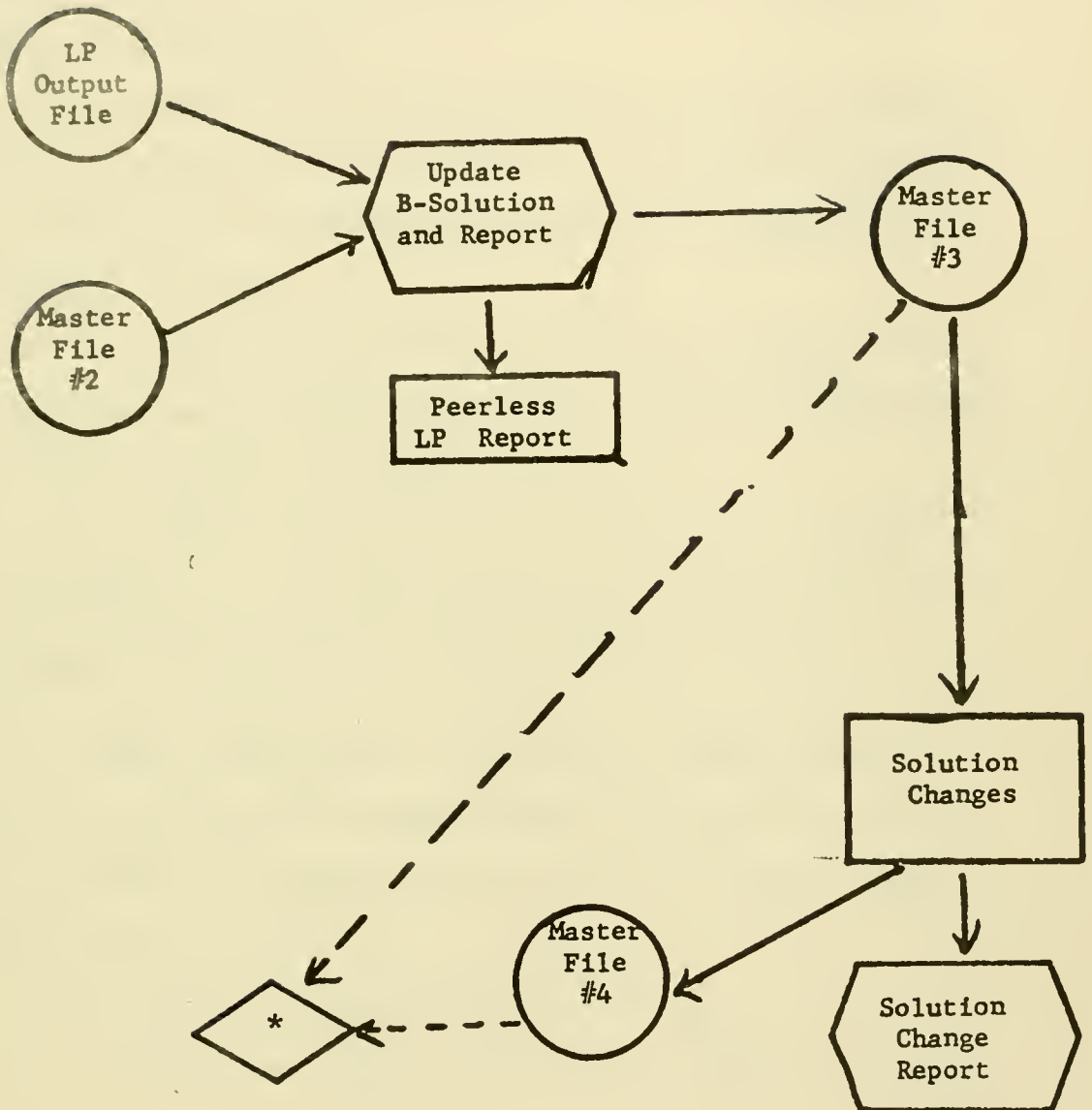




Figure 3 (continued)



\* pick one to replace  
Master File #1





4) Produce LP Input File. The Extended Master File is passed and a tape acceptable to the remote LP code is written. This program was to exist in three versions:

a) Produce full input tape for 1107 code. Each coefficient becomes a card image in 1107 format. Each column bound becomes a new row and a coefficient card image and a right-hand-side element card image.

b) Produce change tape for 1107 code. As above, but, by comparing against Master File A-model, program suppresses card images which have not changed since last run.

c) Produce full input tape for 360 code. As a) above, but bounds do not become new rows; rather, they are held in one special row acceptable as input to the 360 LP code.

5) Compare coefficients. A comparison is made between the Master File A-model and the Extended Master File (drawn, of course, from the B-model). Depending on the setting of a switch, this comparison results in either;

- a) Report of changed coefficients; or
- b) Report of prices outside their C-ranges.

6) Check inconsistencies. Performs the function called "Monitor Inconsistencies" above, using the Extended Master File as input.

7) Produce row list. The Extended Master File is sorted in row-column order and printed.



8) Dump Master File. The B-model of the Master File is printed verbatim. This is used both as a column listing of the model and as a model dump after updating.

9) Update B-solution and report. The LP Output Tape is scanned and information collected by column. This collected information is then inserted into the B-solution area of the Master File. Each updated B-solution line is printed. Because of the format of the Master File, these printed lines become the Peerless LP report. There were to be two versions of this routine:

a) Process 1107 output. This version would have to associate four pieces of information with each column:

- i) Column solution information
- ii) Row solution information for special rows created as bounds
- iii) Post-optimality information by column
- iv) As iii) for rows.

b) Process 360 output. As a) but types ii) and iv) not required because of use of bounded variable algorithm.

10) Print Changes. Described above as "Print Solution Change Report."

In addition to the major modules described above, several others had been designed and partially programmed by December, 1967. These were:

11) Extract price information from PYRAMIDS.



- 12) Produce control report from PYRAMIDS.
- 13) Manipulate prices.
- 14) Produce special reports (table-driven).

Testing of the LP Support System and Parallel Operation of  
the Planning System

Testing of the LP support system and first use of the planning system were carried out together, because it was felt that there could be no better test of the support system than coping with an actual model in a closely simulated planning context. Accordingly, testing of the whole system began, even though it was far from complete.

At the outset we had one stroke of good luck. A 360/50 with 138K bytes of core was found in Cedarton itself. The company leasing the machine (call it the Nonpareil Company) had already brought the 360 LP code, MPS/360, to fully usable status and was willing to let Peerless use several hours per month on very reasonable terms. The availability of MPS/360 significantly reduced the programming required for many of the modules described previously. More important, the "remote" machine was now only 20 minute's drive from Peerless. The tape-carrying procedure required by the system began to look more and more feasible.

One complication arose. The Peerless equipment used 90-column cards and 7-track tapes, while the Nonpareil equipment used 80-column cards and 9-track tapes. This problem was resolved when Peerless agreed to subsidize Nonpareil to the extent of one 7-track tape unit, and, in addition, installed one IBM Key punch on the Peerless premises.



Another minor problem was the difference in character codes between the UNIVAC and IBM equipment. This was handled by substituting a non-standard conversion table for the normal one built into UNIVAC software. In short, data transmission problems were solved reasonably quickly.

Operating procedure at Nonpareil: The operating procedure at Nonpareil became a well-established routine:

- 1) Mount LP Input File on 7-track drive.
- 2) Run MPS CONVERT routine to convert LP problem to internal format on a new tape file PROBFIL.
- 3) Run MODIFY routine to enter any changes to model (usually errors detected and punched after the preparation of the LP Input File).
- 4) Run SETUP routine to prepare to solve.
- 5) Run INSERT routine to insert optimal basis from last run.
- 6) Run PRIMAL routine to solve.
- 7) Run SOLUTION routine to write solution information on LP Output Tape.
- 8a) (If infeasible) Run TRACE routine for diagnostic information; or
- 8b) (If unbounded) Skip to 9; or
- 8c) (If feasible-optimal) Run RANGE routine for C-ranges, etc.
- 9) Run COBOL program (written for the purpose) to print LP Output Tape and copy the relevant subset onto the 7-track drive (where a blank tape should have been mounted during PRIMAL) for carrying back to Peerless.
- 10) Examine output. If infeasible, unbounded, or unreasonable, correct errors and return to step 3. Otherwise, go home.





It should be noted that all the above steps (except for numbers 1 and 10) are performed automatically via the MPS/360 control language and the OS/360 Job Control Language.

In early runs, the whole procedure required an average of three or more tries on the machine, 2 hours of 360/50 time, and 10 hours of effort by each of two or three men. By December, 1967, error detection and correction and general knowledge of the model had progressed so that a typical Nonpareil run required one or two tries, a total of 45 minutes of computer time, and perhaps 6 man-hours of effort.

The timing figures given are for the complete model which was in flux throughout the testing period, but which averaged 700 rows and 2100 columns. Some of the problems encountered in debugging the whole system were:

1) Infeasibility: because of the model structure, infeasibility was usually the result of errors in the change cards. Because of the structure of MPS/360, such errors were easy to trace. But each occurrence forced additional delay.

2) Unbounded Solutions: change card errors were again responsible for most unbounded solutions. However, MPS (or at least the version we used) had no facility for revealing which variable was being brought into solution at the time unboundedness was detected. Our first cut at ameliorating this problem was to modify the "Prepare LP Input Tape" procedure to supply a large upper bound for all variables



without natural upper bounds. Then any unbounded solutions were easily traced after optimality. Our second approach also involved a modification to "Prepare LP Input Tape." MPS permits the definition of a new row as the linear combination of any two other rows. We defined such a row to be identical to the objective function, but to be a less-than constraint with a right-hand-side value roughly four times the largest expected objective function value. Thus, when an unbounded solution occurred, the next variable entered into solution raised the extra row to its maximum value and, there being no further way to increase the objective function, the simplex procedure terminated. The trace of iterations leading to solution would then have, as its last entry, the identification of the unbounded variable. The advantage of this method over the first is that it would typically waste less time. That is, the detection of an unbounded solution terminated the simplex procedure.

3) Huge volume of data input: Our preliminary estimates were that, on average, 200 to 500 prices and bounds would change between runs. In fact, running on a weekly cycle (with the option of running sooner if required), we found that 700 to 1200 numbers had to be input for each run. The major cause of excess data input was that the product managers found it easier (or at least safer) to send in, as changes, every price and bound under their control, whether actually changed or not. This put a heavy load on the time and patience of everyone concerned in the input process, not least the product managers themselves.



The long-term solution, of course, was to use the PYRAMIDS file as a data source, thus eliminating almost all manual input. In the short run, however, we designed a set of computer-prepared input forms, so that the product managers could see what the old value of each price or bound was as they were writing in new values. This was expected to reduce changes to the originally estimated level, but there were enough technical problems in producing such input forms so that this feature was never fully implemented.

4) Consistently incorrect coefficients: System testing uncovered what was apparently a long-standing disagreement between the "official" cut-out yields and the yields used by provisioning to predict primal production. The "official" yields were re-worked and entered into the model four times, but the model was never able to be even qualitatively as accurate as the provisioners' estimates. There was a carefully controlled test in which the "official" yields operated upon actual hog kill experience for a week, and even then there was only fair agreement between actual production and model predictions. The "official" yields were being reworked for the fifth time when work on the project was suspended.

There were many other problems -- human, hardware, and software -- but the four above were the major obstacles. There were also several benefits, but the outstanding gain came from the involvement of Peerless personnel in the model-building and error-tracing processes. The Process Design group was the greatest beneficiary, but, as each new run



was examined and criticized, even the provisioners and product managers gained insight into the hog-to-final-product process. There is some evidence that this effect, at least, will be long-term help to Peerless.

### The End of the Project

Financial difficulties forced Peerless to cancel all projects "not now fully implemented" in December, 1967. The LP-based planning system fell into this category and was accordingly "suspended indefinitely." But, as always, the classification of the planning system as "not now fully implemented" was a human decision -- in this case, a decision of the Chief Provisioner. His stated reason was that, given Peerless' very tight cash position, he did not have enough maneuvering room to exploit the LP recommendations, even if he could rely on them -- and the fact that the very important yield coefficients were in their fifth re-work was evidence enough that he could not rely on the LP.

There were several contributing factors of which two should be cited:

First, the long turn-around, high error rate, and inability to get good predictions of primal production (all of which we emphasize, were improving rapidly with time) had allowed the provisioners to avoid confronting the question of just how much help the system could be as a planning aid. They were therefore uncommitted.





Second, parallel operation of two systems is a meaningless exercise when the users have never really had enough time to keep the old system running smoothly. This was very nearly the case at Peerless. The additional time required to run the new system in parallel was a far more burdensome cost than the additional money.

Indeed, the only way that all the problems could have been solved would have been for the provisioners to take responsibility for the accuracy of data input and the smooth operation of the support system. However, there is a clear tendency for people to prefer responsibility for an overall (human-generated) plan to responsibility for the numbers on which a (machine-generated) plan is based. Some of the reasons are obvious. First, human plans have the characteristic that the consequences of errors tend to be proportional to the magnitude of mistakes, while a machine-generated plan has the potential for a very small error (in input data) to produce profound errors in the plan. Second, in this particular complex planning scheme, it is hard to predict what effect on the plan will be caused by a relatively minor decision about prices, bounds, and the like. It may be that this planning system gave the provisioners too much responsibility.

Shortly after the planning system was suspended, the provisioners evolved a scheme which has some of the potential of the LP system and many fewer problems. Starting with each primal, manual calculations are made of the potential profit for each possible way of allocating that primal to production. These profit figures are then used in mak-



ing allocation decisions. Such a scheme, while it does not take account of interactions and is therefore surely suboptimal, will be, we hope, at least livable, and certainly better than what existed before the LP-based planning system was initiated.

### In Conclusion

This paper provides documentation of the steps and pitfalls in the design of a system to make LP a useful technique for managers charged with day-to-day production scheduling decisions. The "ideal" system is offered as a model of what such a system can be. As important, the actual system, while not now in use, demonstrates that such a system can be constructed even when severe resource limitation exists.



Bibliography

1. Bowman, E.H. and R.B. Fetter, Analysis for Production and Operations Management, Irwin, Homewood, Illinois. 1967.
2. Holt, C. C., F. Modigliani, J. F. Muth and H. A. Simon, Planning Production, Inventories, and Work Force, Prentice-Hall, Englewood Cliffs, New Jersey. 1960.
3. Hadley, G., Linear Programming, Addison-Wesley, Reading, Mass. 1962.
4. Vajda, S., Mathematical Programming, Addison-Wesley, Reading, Massachusetts. 1961.
5. Forrester, J. R., Industrial Dynamics, M.I.T. Press, Cambridge, Massachusetts. 1962.
6. Boyd, D. F. and H. S. Krasnow, "Economic Evaluation of Management Information Systems," IBM Systems Journal, Vol. 2 (1963), pp. 2-23.
7. Duncan, A. J., Quality Control and Industrial Statistics, Irwin, Homewood, Illinois. 1965.
8. Emery, J. C., "Organizational Planning and Control: Theory and Technology," Ph.D. Dissertation, M.I.T. 1965 (Management).
9. Carroll, D. C., "On the Structure of Operational Control Systems," Sloan School Working Paper No. 167-66, M.I.T., Cambridge, Mass. 1966.
10. Snyder, J. C., "Programmed Profit Analysis for Hog Fabrication," IBM Meat-Packing Symposium, Endicott, New York, April 1964.
11. Armbruster, W. J. and J. C. Snyder, "Programmed Profit Analysis for Sausage Manufacturing," Purdue University Research Bulletin No. 800 (November 1965), Lafayette, Indiana.
12. Snyder, J. C. and C. E. French, "Disassembly-assembly Models for Meat-Packing Management," Purdue University Research Bulletin No. 764 (June 1963), Lafayette, Indiana.
13. Swackhamer, G. L. and J. C. Snyder, "A Management Control System for Processed Meat Firms," Purdue University Research Bulletin No. 830 (August 1967) Lafayette, Indiana
14. Adler, R. B., L. J. Chu, and R. M. Fano, Electromagnetic Energy Transmission and Radiation, Wiley, New York 1960.
15. International Business Machines Corporation, "MPS/360 Application Description.
16. Sprague, C. R., "Aggregate Production Scheduling by Linear Programming with Variable Planning Interval," Ph.D. Dissertation, M.I.T.



APPENDIX

Sample System Artifacts

1. Sample Dump of the B-Section of the LP Master File

1	CL0525	B 1	0415	-1.	0926	.8031	1051
2	SB A	35-UP	OTHER GR SK HAM	BS	27.001	.	.
3	CL0526	B 0	0421	-1.	0701	0.1	0702
4	CL0526	B 0	0706	0.1	0707	0.1	0708
5	CL0526	B 0	1002	0.0278	1050	0.086	1051
6	CL0526	B 1	1059	0.0018	1060	0.0071	1502
7	SB A	2-25-DWN	C CAN GR SKHM	BS	132.089	.	.
8	CL0527	B 1	0422	-1.	0926	.7294	1051
9	SB A	2 25-UP	OTHER GR SKDHAM	BS	24.855	.	.
10	CL0529	B 0	0401	-1.	0701	1.	1001
11	CL0529	B 1	1052	0.131	1053	0.042	1054
12	SB A	8-12	C CAN GR SK HAM	LL	.	.	.08642-
13	CL0530	B 0	0402	-1.	0701	.1600	0702
14	CL0530	B 0	1050	0.066	1051	0.089	1052
15	CL0530	B 1	1060	0.0071	1502	99999.	.
16	SB A	12-14	C CAN GR SK HAM	LL	.	.	.03193-
17	CL0531	B 0	0403	-1.	0703	0.54	0704
18	CL0531	B 0	1051	0.089	1052	0.131	1053
19	CL0531	B 1	1502	99999.	.	.	.
20	SB A	14-16S	C CAN GR SK HAM	LL	.	.	.03555-
21	CL0532	B 0	0405	-1.	0704	0.22	0705
22	CL0532	B 0	1050	0.066	1051	0.089	1052
23	CL0532	B 1	1060	0.0071	1502	99999.	.
24	SB A	16-18S	C CAN GR SK HAM	BS	531.362	.	.
25	CL0533	B 0	0407	-1.	0706	0.66	0707
26	CL0533	B 0	1051	0.089	1052	0.131	1053
27	CL0533	B 1	1502	99999.	.	.	.
28	SB A	18-20S	C CAN GR SK HAM	LL	.	.	.00856-
29	CL0534	B 0	0409	-1.	0707	0.43	0708
30	CL0534	B 0	1050	0.066	1051	0.089	1052
31	CL0534	B 1	1060	0.0071	1502	99999.	.
32	SB A	20-22S	C CAN GR SK HAM	BS	541.004	.	.
33	CL0535	B 0	0411	-1.	0709	.7700	0710
34	CL0535	B 0	1051	0.089	1052	0.131	1053
35	CL0535	B 1	1502	99999.	.	.	.
36	SB A	22-24	C CAN GR SK HAM	BS	74.280	.	.
37	CL0536	B 0	0401	-1.	0723	0.1	1001
38	CL0536	B 0	1052	0.1478	1053	0.0464	1054
39	CL0536	B 1	1502	99999.	.	.	.
40	SB A	8-12	HT CAN GR SK HAM	LL	.	.	.41492-
41	CL0537	B 0	0402	-1.	0723	0.25	0724
42	CL0537	B 0	1002	0.0287	1050	0.066	1051
43	CL0537	B 1	1059	0.0016	1060	0.0064	1064
44	SB A	12-14	HT CAN GR SK HAM	BS	67.364	.	.
45	CL0538	B 0	0403	-1.	0726	0.2	0727



.0798	1052	.1121	1502	99999.	3301	.667
.01000-	CL0522	LL	.02494	CL0352	LL	
.100	0703	0.1	0704	0.1	0705	0.1
0.1	0709	0.1	0710	0.1	1001	0.0026
0.139	1052	0.132	1053	0.06	1054	0.1005
99999.						
.07219-	CL0323	UL	INFINITY		NONE	
.1621	1052	.1025	1502	99999.	3301	.667
.34452-	CL0366	LL	INFINITY		NONE	
0.0026	1002	0.0378	1050	0.066	1051	0.089
0.0412	1059	0.0018	1060	0.0071	1502	99999.
0.61	0703	0.23	1001	0.0026	1002	0.0278
0.131	1053	0.042	1054	0.0412	1059	0.0018
0.46	1001	0.0026	1002	0.0278	1050	0.066
0.042	1054	0.0412	1059	0.0018	1060	0.0071
0.56	0706	0.22	1001	0.0026	1002	0.0278
0.131	1053	0.042	1054	0.0412	1059	0.0018
.00066-	CL0742	LL	.00183	CL0352	LL	
0.34	1001	0.0026	1002	0.0278	1050	0.066
0.042	1054	0.0412	1059	0.0018	1060	0.0071
0.46	0709	0.11	1001	0.0026	1002	0.0278
0.131	1053	0.042	1054	0.0412	1059	0.0018
.01138-	CL0311	UL	.01084	CL0312	LL	
0.23	1001	0.0026	1002	0.0278	1050	0.066
0.042	1054	0.0412	1059	0.0018	1060	0.0071
.00550-	CL0360	LL	.00423	CL0313	LL	
0.0023	1002	0.0287	1050	0.066	1051	0.089
.0514	1059	0.0016	1060	0.0064	1064	.0290
0.15	0725	0.35	0726	0.25	1001	0.0023
0.089	1052	0.1478	1053	0.0464	1054	.0514
.0290	1502	99999.				
.00401-	CL1951	UL	.00137	CL0352	LL	
0.28	0728	0.3	0729	0.22	1001	0.0023



Sample Listing of Change Cards Submitted to  
"Update Coefficients"

CL8246RW2251	1.
CL8246RW8860	-1.
CL8247RW1500	-99.99
CL8247RW8047	1.
CL8247RW8160	-1.
CL8248RW1500	-0.0728
CL8248RW8048	1.
CL8248RW8860	-1.
CL8248RW1501	25.
CL8249RW1500	-0.1324
CL8249RW8049	1.
CL8249RW8860	-1.
CL8249RW1501	24.
CL8250RW1500	-99.99
CL8250RW8050	1.
CL8250RW8860	-1.
CL8252RW1500	-99.99
CL8252RW8052	1.
CL8252RW8860	-1.
CL8254RW1500	-99.99
CL8254RW8054	1.
CL8254RW8860	-1.
CL8256RW1500	-99.99
CL8256RW6002	1.
CL8256RW8860	-1.
CL8257RW1500	-99.99
CL8257RW6003	1.
CL8258RW1500	-99.99
CL8258RW6058	1.
CL8258RW8860	-1.
CL8259RW1500	-99.99
CL8259RW6059	1.
CL8259RW8860	-1.
CL8260RW1500	-0.32
CL8260RW8060	1.
CL8260RW8860	-1.
CL8260RW1501	1.
CL8261RW1500	-99.99
CL8261RW8860	-1.
CL8265RW1500	-0.37
CL8265RW8061	1.
CL8265RW8065	-1.
CL8265RW8860	-1.
CL8265RW1501	45.



Sample Output of the "Monitor Changes" Routine

(Note: this sample taken prior to installation of the "Monitor Price" feature.)

COEFFICIENT CHANGE LIST

10-20-67

COL	ROW	NEW	OLD
0063	1500	-.1655	-.1693
0063	1503	NONE	.0088
0063	6020	.0093	.0100
0064	1500	-.1637	-.1652
0064	1503	NONE	.0083
0064	6020	.0093	.0110
0065	1500	-.1637	-.1652
0065	1503	NONE	.0083
0065	6020	.0093	.0110
0066	1500	-.1637	-.1652
0066	1503	NONE	.0083
0066	6020	.0093	.0110
0067	1500	-.1637	-.1652
0067	1503	NONE	.0083
0067	6020	.0093	.0110
0068	1500	-.1637	-.1652
0068	1503	NONE	.0083
0068	6020	.0093	.0110
0069	1500	-.1637	-.1652
0069	1503	NONE	.0083
0069	6020	.0093	.0110
0070	1500	-.1718	-.1702
0070	1503	NONE	.0105
0070	6020	.0109	.0110
0071	1500	-.1718	-.1702
0071	1503	NONE	.0105
0071	6020	.0109	.0110
0072	1500	-.1718	-.1702
0072	1503	NONE	.0105
0072	6020	.0109	.0110
0073	1500	-.1718	-.1702
0073	1503	NONE	.0105
0073	6020	.0109	.0110
0074	1500	-.1718	-.1702



Sample Model by Row Listing

4600	4218	.2656
4600	4250	.2021
4600	4251	.2221
4600	4600	-1.

4601	4218	.0271
4601	4250	.0288
4601	4251	.0288
4601	4601	-1.

4602	4218	.0881
4602	4250	.0936
4602	4251	.0936
4602	4252	.1240
4602	4602	-1.

4603	4250	.0620
4603	4251	.0620
4603	4603	-1.

4604	4252	.3282
4604	4604	-1.

4605	4252	.0813
4605	4605	-1.

4606	4252	.1216
4606	4606	-1.

4607	4351	.05845
4607	4607	-1.

4608	4360	.05143
4608	4608	-1.

UARCO BUSINESS FORMS - WATERLOO, N.Y.

71436





Sample MPS Control Program

CONTROL PROGRAM COMPILER

0001		PROGRAM
0002		INITIALZ
0057		XFREQINV = 50
0058		XINVERT = 1
0059		MVADR(XDONFS,INFEAS)
0060		MVADR(XDOUNB,MERTES)
0061		MOVE(XPBNAM,"PRFILE")
0062		MOVE(XOLONAM,"PBFIL")
0063		MOVE(XDATA,"NEWLP")
0064		REVISE('SUMMARY')
0065		SETUP("BOUND","ZZZZZZZ","MAX")
0066		MOVE(XOBJ,'RW1500')
0067		MOVE(XRHS,"ZZZ0001")
0068		MOVE(XDATA,'BASIS')
0069	*	BASIS INSERT BLCK (PRESENT IF OLD BASIS)
0070		INSERT
0071		GOTO(DOIT)
0072	*	END BASIS INSERT BLOCK
0073		CRASH
0074	DOIT	PRIMAL
0075		SOLUTION
0076		PUNCH('LIST','VALUE')
0077		RANGE
0078		EXIT
0079	INFEAS	TRACE
0080	MERTES	STATUS
0081		SOLUTION
0082		PUNCH('LIST','VALUE')
0083		EXIT
0084		PEND



5. Portion of Sample Iteration Log

EXECUTOR.

	ITER NUMBER	NUMBER NONOPT	VECTOR OUT	VECTOR IN	REDUCED COST	FUNCTION VALUE
	117		1363	1360	.05646-	2215.11
	118		1516	1252	.00004-	2215.33
M	119	35	1728	1663	.03923-	2217.28
M	120	37	1252	1207	.01636-	2217.50
	121		1727	1544	.00235-	2217.50
M	122	11	1485	1485	.00001	2217.93
	123		1207	876	.00001-	2218.13
	124		782	1711	.00775-	2218.16
	125		1656	1652	.00313-	2218.17
M	126	10	1714	1210	.00426-	2218.19
M	127	6	1186	1186	.00000	2218.42
	128		1185	1185	.00000	2218.65
	129		1412	1494	.00000-	2218.78
	130		1573	1574	.01032-	2218.80
	131		906	746	.00000-	2218.81
M	132	3	1680	1681	.00041-	2218.81
	133		746	759	.00000-	2218.82
	134		1652	1656	.00110-	2218.82
M	135	5	759	771	.00364-	2218.84
	136		1650	1651	.00041-	2218.84
OPTIMAL SOLUTION						

## 7. Portion of Sample MPS Output (Solution Section)

## EXECUTOR.

NUMBER	CLCUMN.	AT	...ACTIVITY...	..INPUT COST..	..LOWER LIMIT
1222	CL2706	ES	40.00000	.	.
1223	CL2707	LL	400.00000	.25400	400.00000
1224	CL2708	LL	40.00000	.27880	40.00000
1225	CL2709	LL	60.00000	.29000	60.00000
1226	CL2720	ES	569.89414	.	.
1227	CL2721	ES	117.06586	.	.
1228	CL2722	LL	.	.	.
1229	CL2723	ES	231.16000	.	.
1230	CL2724	LL	.	.	.
1231	CL2725	LL	.	.	.
1232	CL2726	ES	133.95600	.	.
1233	CL2727	LL	.	.	.
1234	CL2728	LL	.	.	.
1235	CL2729	LL	.	.	.
1236	CL2730	ES	35.12573	.	.
1237	CL2731	ES	143.48227	.	.
1238	CL2732	ES	87.32000	.	.
1239	CL2733	LL	.	.	.
1240	CL2734	LL	.	.	.
1241	CL2735	ES	137.34000	.	.
1242	CL2736	LL	.	.	.
1243	CL2737	LL	.	.	.
1244	CL2738	ES	66.32400	.	.
1245	CL2739	ES	132.64600	.	.
1246	CL2740	LL	.	.	.
1247	CL2741	LL	.	.	.
1248	CL2742	ES	44.21600	.	.
1249	CL2743	ES	523.92000	.	.
1250	CL2744	LL	.	.	.
1251	CL2750	UL	40.00000	.68000	20.00000
1252	CL2751	UL	80.00000	.56000	40.00000
1253	CL2752	UL	80.00000	.63000	40.00000
1254	CL2753	EQ	.	.	.
1255	CL2754	UL	1200.00000	.53000	600.00000
1256	CL2755	UL	200.00000	.58000	100.00000
1257	CL2756	UL	120.00000	.53000	60.00000
1258	CL2757	UL	160.00000	.52000	80.00000
1259	CL2758	UL	80.00000	.48000	40.00000
1260	CL2759	UL	120.00000	.53000	60.00000
1261	CL2760	UL	60.00000	.47000	20.00000
1262	CL2761	UL	120.00000	.46000	60.00000
1263	CL2762	EQ	40.00000	.46000	40.00000
1264	CL2763	EQ	480.00000	.41000	480.00000
1265	CL2764	EQ	400.00000	.36000	400.00000
1266	CL2850	ES	198.23463	.06750	.
1267	CL2851	ES	63.16647	.27000	.
1268	CL2852	ES	32.01310	.01950	.
1269	CL2853	ES	241.51800	.37000	.
1270	CL2854	LL	.	.15000	.
1271	CL3000	ES	72.61469	.	.
1272	CL3001	ES	1157.46558	.	.

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UPPER LIMIT.    .REDUCED COST.

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99999.00000

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600.00000

.02116-

120.00000

.00433-

120.00000

.06127-

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.10847

80.00000

.08077

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.46691-

1200.00000

.09804

200.00000

.09906

120.00000

.08710

160.00000

.10386

80.00000

.04571

120.00000

.15766

60.00000

.10072

120.00000

.10538

40.00000

.11243

480.00000

.04239

400.00000

.00366

99999.00000

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.01141-

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## 8. Portion of Sample MPS Output (Ranges Section)

## EXECUTOR.

LINE#	COLUMN	AT	...ACTIVITY...	..INPUT COST..	..LOWER LIMIT	..UPPER LIMIT
1214	CL265E	LL	.	.	.	99998.94830
1216	CL2700	LL	39.99994	.46000	19.99997	39.99995
1217	CL2701	LL	.	.29000	.	39.99999
1218	CL2702	LL	199.99983	.33340	199.99983	399.99981
1219	CL2703	LL	1199.99901	.33340	1199.99901	1599.99877
1220	CL2704	LL	199.99983	.33340	199.99983	399.99981
1221	CL2705	LL	.	.	.	99998.94830
1223	CL2707	LL	399.99982	.25400	399.99982	599.99981
1224	CL2708	LL	39.99999	.27880	39.99999	119.99998
1225	CL2709	LL	59.99994	.29000	59.99994	119.99993
1228	CL2722	LL	.	.	.	99998.94830
1230	CL2724	LL	.	.	.	99998.94830
1231	CL2725	LL	.	.	.	99998.94830
1233	CL2727	LL	.	.	.	99998.94830
1234	CL2728	LL	.	.	.	99998.94830
1235	CL2729	LL	.	.	.	99998.94830
1239	CL2733	LL	.	.	.	99998.94830

LCWER ACTIVITY	..UNIT COST..	..UPPER COST..	LIMITING	AT
UPPER ACTIVITY	..UNIT COST..	..LOWER COST..	PROCESS.	AT
817.06519-	.	INFINITY-	CL2721	LL
.	.	.	CL2659	LL
34.58343	.13563-	.32437	CL2251	LL
123.49858	.13563	INFINITY	CL2251	UL
.	.06463	INFINITY-	CL2650	LL
19.70951	.06463-	.35463	CL2600	LL
458.41723-	.00400	INFINITY-	CL2256	LL
780.10356	.00400-	.33740	CL2720	LL
541.58247	.00400	INFINITY-	CL2256	LL
2204.46788	.00400-	.33740	CL2256	UL
164.24483	.00400	INFINITY-	CL2730	LL
346.05260	.00400-	.33740	CL2731	LL
19.78978-	.	INFINITY-	CL2602	LL
39.99997	.	.	CL2706	LL
448.80744-	.02116	INFINITY-	CL2657	LL
496.76113	.02116-	.27516	CL2603	LL
.	.00433	INFINITY-	CL2706	LL
59.78978	.00433-	.28313	CL2602	LL
55.20400	.06127	INFINITY-	CL2251	LL
133.93223	.06127-	.35127	CL2251	UL
35.12570-	.	INFINITY-	CL2730	LL
143.48219	.	.	CL2731	LL
569.89365-	.	INFINITY-	CL2720	LL
231.15988	.	.	CL2723	LL
35.12570-	.	INFINITY-	CL2730	LL
143.48219	.	.	CL2731	LL
569.89365-	.	INFINITY-	CL2720	LL
133.95591	.	.	CL2726	LL
35.12570-	.	INFINITY-	CL2730	LL
133.95591	.	.	CL2726	LL
817.06519-	.	INFINITY-	CL2721	LL
35.12570	.	.	CL2730	LL
569.89365-	.	INFINITY-	CL2720	LL
87.31994	.	.	CL2732	LL

9. Sample Output of "Update B-Solution" and "Report"

L.P. Col. No.	Activity Type	Description	Activity At	Recommended Activity	Reduced Cost
0301	SB B	8-12 HAMS (A PRICE)	LL	.	.00500-
0302	SB B	8-12 HAMS (B PRICE)	LL	.	.02000-
0303	SB B	12-14 HAMS (A PRICE)	LL	.	.00500-
0304	SB B	12-14 HAMS (B PRICE)	LL	.	.01500-
0305	SB B	14-16 HAMS (A PRICE)	LL	.	.00641-
0306	SB B	14-16 HAMS (B PRICE)	LL	.	.01641-
0307	SB B	16-18 HAMS (A PRICE)	LL	.	.00970-
0308	SB B	16-18 HAMS (B PRICE)	LL	.	.02470-
0309	SB B	18-20 HAMS (A PRICE)	LL	.	.00970-
0310	SB B	18-20 HAMS (B PRICE)	LL	.	.02470-
0311	SB B	20-22 HAMS (A PRICE)	UL	207.000	.00512
0312	SB B	20-22 HAMS (B PRICE)	LL	.	.00488-
0313	SB B	22-24 HAMS (A PRICE)	LL	.	.00870-
0314	SB B	22-24 HAMS (B PRICE)	LL	.	.01470-
0315	SB B	24-26 HAMS (A PRICE)	LL	.	.00970-
0316	SB B	24-26 HAMS (B PRICE)	LL	.	.01970-
0317	SB B	26-30 HAMS (A PRICE)	LL	.	.00970-
0318	SB B	26-30 HAMS (B PRICE)	LL	.	.02470-
0319	SB B	30-35 HAMS (A PRICE)	LL	.	.00500-
0320	SB B	30-35 HAMS (B PRICE)	LL	.	.01000-
0321	SB B	35-UP HAMS (A PRICE)	LL	.	.00500-
0322	SB B	35-UP HAMS (B PRICE)	LL	.	.01000-
0323	SB B	25-DOWN 2 CJ HAMS	EQ	30.600	.01279
0350	SB S	8-12 GR SK HAM	BS	47.255	.
0351	SB S	12-14 GR SK HAM	BS	248.715	.
0352	SB S	14-16 GR SK HAM SKR	BS	115.003	.
0353	SB S	14-16 GR SK HAM FLTR	BS	383.819	.
0354	SB S	16-18 GR SK HAM SKR	LL	.	.
0355	SB S	16-18 GR SK HAM FLTR	BS	60.021	.
0356	SB S	18-20 GR SK HAM SKR	BS	89.864	.
0357	SB S	18-20 GR SK HAM FLTR	LL	.	.
0358	SB S	20-22 GR SK HAM SKR	LL	.	.01674-
0359	SB S	20-22 GR SK HAM FLTR	LL	.	.00700-
0360	SB S	22-24 GR SK HAM	BS	208.451	.
0361	SB S	24-26 GR SK HAM	BS	265.750	.
0362	SB S	26-30 GR SK HAM	BS	36.162	.
0363	SB S	30-35 GR SK HAM	LL	.	.00470-
0364	SB S	35-UP GR SK HAM	LL	.	.00470-
0365	SB S	2 25-DOWN GR SK HAMS	LL	.	.01749-
0366	SB S	2 25-UP GR SK HAMS	LL	.	.04012-
0401	SB I	8-12 HAMS	LL	.	.00470-
0402	SB I	12-14 HAMS	LL	.	.00470-
0403	SB I	14-16 HAMS	LL	.	.00470-



Greatest  
Cost  
Limit

Limiting  
Activity

At

Least  
Cost  
Limit

Limiting  
Activity

At

.47500	CL0450	UL	.48000	CL0301	LL
.44500	CL0451	UL	.45000	CL0303	LL
.42500	CL0466	LL	.42500	CL0405	LL
.38799	CL0507	LL	.44637	CL0305	LL
.40000	CL0354	LL	.40065	CL0777	LL
.39500	CL0357	LL	.39705	CL0514	LL
.37800	CL0411	LL	.38242	CL0514	LL
.37000	CL0412	LL	.37800	CL0672	LL
.35500	CL0413	LL	.35970	CL0458	LL

10. Sample Output of "Report Solution Changes"

0054	B	H	LVE	WGT	HUGS	280-30063	BS	181.027	.
0055	A	H	LVE	WGT	HUGS	280-30064	BS	139.463	.
0055	B	H	LVE	WGT	HUGS	280-30064	BS	266.512	.
0056	A	H	LVE	WGT	HUGS	280-30065	BS	106.919	.
0056	B	H	LVE	WGT	HUGS	280-30065	BS	283.129	.
0057	A	H	LVE	WGT	HUGS	280-30066	BS	374.529	.
0057	B	H	LVE	WGT	HUGS	280-30066	BS	864.124	.
0058	A	H	LVE	WGT	HUGS	300-32061	BS	.	.
0058	B	H	LVE	WGT	HUGS	300-32061	BS	4.804	.
0059	A	H	LVE	WGT	HUGS	300-32062	BS	3.744	.
0059	B	H	LVE	WGT	HUGS	300-32062	BS	5.936	.
0060	A	H	LVE	WGT	HUGS	300-32063	BS	22.737	.
0060	B	H	LVE	WGT	HUGS	300-32063	BS	55.301	.
0061	A	H	LVE	WGT	HUGS	300-32064	BS	25.272	.
0061	B	H	LVE	WGT	HUGS	300-32064	BS	63.879	.
0062	A	H	LVE	WGT	HUGS	300-32065	BS	30.441	.
0062	B	H	LVE	WGT	HUGS	300-32065	BS	89.705	.
0063	A	H	LVE	WGT	HUGS	300-32066	BS	133.055	.
0063	B	H	LVE	WGT	HUGS	300-32066	BS	386.663	.
0064	A	H	LVE	WGT	HUGS	320-34061	BS	1.324	.
0064	B	H	LVE	WGT	HUGS	320-34061	BS	1.293	.
0065	A	H	LVE	WGT	HUGS	320-34062	BS	2.764	.
0065	B	H	LVE	WGT	HUGS	320-34062	BS	2.541	.
0066	A	H	LVE	WGT	HUGS	320-34063	BS	4.017	.
0066	B	H	LVE	WGT	HUGS	320-34063	BS	6.267	.
0067	A	H	LVE	WGT	HUGS	320-34064	BS	9.532	.
0067	B	H	LVE	WGT	HUGS	320-34064	BS	23.808	.
0068	A	H	LVE	WGT	HUGS	320-34065	BS	8.107	.
0068	B	H	LVE	WGT	HUGS	320-34065	BS	26.457	.
0069	A	H	LVE	WGT	HUGS	320-34066	BS	37.728	.
0069	B	H	LVE	WGT	HUGS	320-34066	BS	108.262	.
0070	A	H	LVE	WGT	PKRS	300DOWN61	BS	71.611	.
0070	B	H	LVE	WGT	PKRS	300DOWN61	BS	78.001	.
0071	A	H	LVE	WGT	PKRS	300DOWN62	BS	99.331	.
0071	B	H	LVE	WGT	PKRS	300DOWN62	BS	70.054	.
0072	A	H	LVE	WGT	PKRS	300DOWN63	BS	46.713	.
0072	B	H	LVE	WGT	PKRS	300DOWN63	BS	56.394	.
0073	A	H	LVE	WGT	PKRS	300DOWN64	BS	12.484	.

10. Sample Output of "Report Solution Changes"

5.19751-	CL0001	UL	INFINITY	NONE
8.21026-	CL0002	UL	INFINITY	NONE
3.58365-	CL0001	UL	INFINITY	NONE
10.65811-	CL0002	UL	INFINITY	NONE
3.38308-	CL0001	UL	INFINITY	NONE
3.16277-	CL0002	UL	INFINITY	NONE
1.22014-	CL0001	UL	INFINITY	NONE
INFINITY-	NONE		INFINITY	NONE
189.72678-	CL0001	UL	INFINITY	NONE
299.73680-	CL0002	UL	INFINITY	NONE
156.21537-	CL0001	UL	INFINITY	NONE
49.49412-	CL0002	UL	INFINITY	NONE
16.63221-	CL0001	UL	INFINITY	NONE
44.54730-	CL0002	UL	INFINITY	NONE
14.42058-	CL0001	UL	INFINITY	NONE
31.01056-	CL0002	UL	INFINITY	NONE
10.31561-	CL0001	UL	INFINITY	NONE
8.59597-	CL0002	UL	INFINITY	NONE
2.51769-	CL0001	UL	INFINITY	NONE
846.77575-	CL0002	UL	INFINITY	NONE
704.26055-	CL0001	UL	INFINITY	NONE
405.83184-	CL0002	UL	INFINITY	NONE
358.61285-	CL0001	UL	INFINITY	NONE
279.33320-	CL0002	UL	INFINITY	NONE
145.48059-	CL0001	UL	INFINITY	NONE
117.81976-	CL0002	UL	INFINITY	NONE
38.41946-	CL0001	UL	INFINITY	NONE
138.50884-	CL0002	UL	INFINITY	NONE
34.58938-	CL0001	UL	INFINITY	NONE
29.89206-	CL0002	UL	INFINITY	NONE
8.57631-	CL0001	UL	INFINITY	NONE
15.83404-	CL0002	UL	INFINITY	NONE
11.83854-	CL0001	UL	INFINITY	NONE
11.46323-	CL0002	UL	INFINITY	NONE
13.16308-	CL0001	UL	INFINITY	NONE
24.18177-	CL0002	UL	INFINITY	NONE
16.31228-	CL0001	UL	INFINITY	NONE
90.00837-	CL0002	UL	INFINITY	NONE



11. Sample Output of "Monitor Inconsistencies"

0306	.46	B 14-16 HAMS (8 PRICE)	INCONSISTENT
0366	.0	S 2 25-UP GR SK HAMS	INCONSISTENT
0660	.0	P 14-16. SMO SKLS WA FC HM	INCONSISTENT
3613	0.0	P FRESH PICNIC CHUNKS	INCONSISTENT
4100	0.	I 1L-18 REG LN	INCONSISTENT
8015	-99.99		INCONSISTENT
8017	-99.99		INCONSISTENT
8020	-99.99		INCONSISTENT
8050	-99.99		INCONSISTENT
8059	-99.99		INCONSISTENT
8060	-99.99		INCONSISTENT
8061	-99.99		INCONSISTENT
8065	-99.99		INCONSISTENT
8121	0.	I 20% PK TRIM (21)	INCONSISTENT
8122	0.	I PICNIC TRIM (22)	INCONSISTENT
8140	0.	I 40% LEAN BF (40)	INCONSISTENT
8142	0.	I 85% BF CHO BRIS (42)	INCONSISTENT
8145	0.	I 60% LEAN BEEF (45)	INCONSISTENT
8152	0.	I 70% LEAN BF (52)	INCONSISTENT
8158	0.	I 20% PK TRIM (58)	INCONSISTENT
8167	0.	I 80% LEAN BF (67)	INCONSISTENT
8266	.4221	O PIC CHUNKS (66)	INCONSISTENT

0022 INCONSISTENT

NO DESCRIPTION



## REFERENCES

1. Clark C. Abt et al., *Survey of the State of the Art: Social, Political, and Economic Models and Simulations* (Cambridge, Mass.: Abt Associates, November 1965), pp. 64-65.
2. Arnold E. Amstutz, "A Marketing Oriented Behavioral Theory of Interactions within Consumer Product Markets," unpublished Ph.D. Dissertation, MIT, June 1965.
3. Arnold E. Amstutz and Henry J. Claycamp, "The Total Market Environment Simulation: An Approach to Management Education," *Industrial Management Review*, 5, 47-60 (spring 1964).
4. Frederick E. Balderston and Austin C. Hoggatt, *Simulation of Market Processes*, Berkeley, Institute of Business and Economic Research, University of California, 1962.
5. C. West Churchman, "An Analysis of the Concept of Simulation," in Austin Curwood Hoggatt and Frederick E. Balderston, editors, *Symposium on Simulation Models: Methods and Applications to the Behavioral Sciences* (Cincinnati: Southwestern Publishing Co., 1963), p. 12.
6. R. M. Cyert, J. G. March, C. G. Moore, "A Specific Price and Output Model," *A Behavior Theory of the Firm* (Englewood Cliffs, New Jersey: Prentice-Hall, 1963), pp. 128-48.
7. John A. Howard and William M. Morganroth, "A Positive Model of Executive Decision," *Management Science* (forthcoming).
8. Philip Kotler, "Competitive Strategies for New Product Marketing Over the Life Cycle," *Management Science*, 12, 104-119 (December 1965).
9. Alfred A. Kuehn and Michael J. Hamburger, "A Heuristic Program for Locating Warehouses," *Management Science*, 9, 643-66 (July 1963).
10. George W. Morgenthauer, "The Theory and Application of Simulation in Operations Research," in Russell L. Ackoff, editor, *Progress in Operations Research* (New York: John Wiley), p. 367.
11. Guy H. Orcutt et al., *Micro-Analysis of Socio Economic Systems: A Simulation Study* (New York: Harper, 1961).
12. Harvey M. Shycon and Richard B. Maffie, "Simulation—Tool For Better Distribution," *Harvard Business Review* (November-December 1960).
13. *Simulmatics Media Mix: Technical Description* (New York: Simulmatics Corporation, October 1962).
14. A. M. Turing, "Computing Machinery and Intelligence," *MIND*, pp. 433-60 (October 1950).







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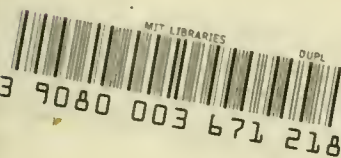


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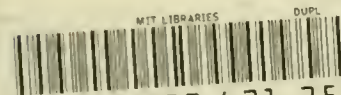


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