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The application of operations research techniques to a public school system's lunch program suggests a possible solution to the problem of rapidly increasing program costs. A computer-assisted menu planner was developed which generated a monthly set of menus satisfying nutritional and Federal standards, and food demand cycles. When compared to the menus actually used in the school system, the computer-planned menus offered a greater variety, had less price fluctuation, and reduced the average cost per serving by approximately 10 percent. The menu generator was then combined with a set of inventory models to determine the ordering quantities and ordering intervals which would result in the minimum cost. The results of this procedure suggest that substantial savings are possible through the use of these models, both in reduction of direct costs and in reduction of clerical effort. (JH)

TAKING THE HEAT OFF THE SCHOOL LUNCHROOM*

by

Raymond P. Lutz, Clark A. Mount-Campbell, and Kenneth S. Wynn

INTRODUCTION

"What did you have to eat today at school, Son?" Such a question will probably elicit as informative and enlightening a reply as "What did you learn in school this afternoon?" One reason for a vague response is that much of what is done in the cafeteria is no more evident to the student than the interrelationship of his daily lessons and learning theory. Even though the child may be impressed by a particular item on the menu that day, there is far more to operating the school lunch program than is apparent to the consumer of the final product. Just as in most industrial situations, the product reaching the consumer is the result of the efforts of many people dedicated to providing the best possible output within the constraints placed upon them. As in the industrial environment, the principle constraints governing the lunchroom supervisors are those associated with demand, finances, and legal restrictions.

School lunches are made available to children through the National School Lunch Act which states, in part:

> It is the policy of Congress, as a measure of national security to safeguard the health and well-being of the

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> Nation's children...by assisting the state, through grants-in-aid and other means, in providing an adequate supply of foods and other facilities for the establishment, maintenance, operation and expansion of nonprofit school lunch programs. (15, p. i)

Taking this charge from Congress, most local school districts, working with their state coordinating agencies, have established and maintained a school lunch program. Unfortunately, this program has become far more "nonprofit" than Congress apparently envisioned. The villain in this instance is not unfamiliar to any Industrial Engineer; it is a squeeze between a low market price and high labor and material costs.

Every rise in the school lunch price either excludes another segment of the school population or places an additional burden on the taxpayers if those unable to pay for their lunch are to be fed. Yet, these are the very children who are in greatest need of the nourishment provided by the school lunch program.

The cafeteria operation which was once financially self-sustaining has suddenly turned into a nightmare for many school administrators. In the past the schools have been able to use part-time help, usually housewives, at very low cost. However, Congress has now included these workers in the latest Federal Minimum Wage Act and in some cases this doubled the rate of compensation. Such an increase was especially difficult to overcome in an operation which was largely designed, both physically and psychologically, for intensive use of hand labor.

The cost of food has also risen. At one time the bulk of the menu could be prepared using Federally donated food stuffs; however, the large and regular shipments of meat and poultry seem to be a thing of the past. A few items, such as rice, beans, peanut butter, and butter, are still available, but it seems only a matter of time until food subsidies will cease.

In addition to the general price rise of food, costs are also being forced up by the mobility of society itself. People moving around the country take their food tastes with them, and since it is a stated policy to use the school lunch as an educational enrichment experience for the child (15, p. iii), the menus now exhibit more variety than ever before. Spaghetti and pizza are now served almost as frequently in New Mexico as enchiladas and tamales. While increased costs do not have to be a direct result of increased variety, such a result is quite common. Finally, the general increase in the standard of living has also had its effect on menu costs, for the food demand patterns have been upgraded.

The combined effect of this cost-price squeeze has resulted in severe losses for a number of school systems. This paper describes a study which was performed for a school system in order to attempt to reduce the costs of the school lunch program through operations research techniques.

COMPUTER ASSISTED MENU PLANNING

In order to identify problem areas which were mutually acceptable for more detailed investigation, a gross study was made of the entire school lunch system. Visits were made to the cafeterias and warehouse facilities to get an impression of the operating procedures, investment in capital equipment, layout and frequency of usage of equipment, and the composition and duties of the labor force. While it was evident that detailed analyses could profitably be conducted in several of these areas, it was decided that the initial effort would concentrate on the general problem of inventory control.

The problem of inventory control was initially divided into two segments:

a) computer-assisted menu planning, and b) food demand forecast modeling. It was thought that some of the recent work in computer-assisted menu planning, such as the linear programming technique reported on by Gue (10) at the 1966 Conference might be used. This technique was constructed to satisfy a minimum (or maximum) amount of nine nutrients. However, the constraints which were present in the school lunch program required a different formulation from those used previously. The statutory requirements for a TYPE A lunch proved to be the principal deterrent to using existing computer programs. The TYPE A lunch requirements are specified in Public Law 396, 79 Congress, 1946, National School Lunch Act, and these requirements must be adhered to if a school system's lunch program is to qualify for Federal assistance. The minimum requirements for the TYPE A lunch are shown in Figure #1. These requirements are much less stringent than Gue (10, p. 395) was bound by. While it might be desirable to establish some minimum nutritional level for the school lunch, especially in those cafeterias serving disadvantaged children, until these standards are established, linear programming methods seem excessively complex. Reducing the complexity of any proposed computer-assisted menu preparation method was felt to be critical if the lunch program personnel were to use the method for monthly menu generation and inventory simulations. Consequently, a dynamic programming solution was proposed. (13, p. 91)

Definition of Terms. Before explicitly going into the technique used to generate the school lunch menus, it might be appropriate to define some of the terms used. The menus were planned in much the same way that any housewife or cafeteria supervisor would perform this function. A recipe file was established listing menu items suggested by various governmental agencies and

FIGURE #1. REQUIREMENTS FOR THE TYPE A LUNCH*

Every day the School Lunch Menu should include as a Minimum:

A. Milk--One-half pint of fluid whole milk as a beverage. Milk must meet the 3.5% butterfat requirement. Only Grade A pasteurized milk is to be served.

B. Meat or Meat Substitute (Protein Rich Foods)--Lean meat, fish, or poultry--2 ounces, edible portion as served.

Cheese--2 ounces

Eggs-- one whole egg or its equivalent in whole dried eggs.

Dried Beans or Peas--1/2 cup, cooked measure. Note: Dried beans or dried peas can be counted as protein-rich food or as a vegatable, but not as both in the same lunch.

Peanut Butter--4 Tablespoons or 1/4 cup.

To be counted in meeting this requirement, these foods (or any equivalent quantity of any combination of the above food) must be served in a main dish or in a main dish and one other menu item. (These amounts are doubled for Secondary School Children.)

C. Vegetables and/or fruit--3/4 cup. This requirement should be met by two or more servings of vegetables or fruit, or both. ... Full-strength vegetable or fruit juice may be counted to meet not more than one-fourth cup of this requirement. A fruit or vegetable rich in Vitamin C should be served every day and a fruit or vegatable rich in Vitamin A should be served at least twice a week. ...

D. Bread--One slice of whole-grain or enriched bread; or a serving of cornbread, biscuits, rolls, muffins, etc., made of whole-grain or enriched meal or flour. Crackers and tortillas that are not made from enriched flour or meal do not meet the bread requirement; therefore, when they are served, they should be served in addition to an enriched bread.

E. Butter or Fortified Margarine--2 teaspoons. Butter may be served separately, may be spread on bread, or may be used in cooking.

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*15, pp. 4-5.

chosen by local personnel through their experience in their particular environment. A menu item was the combination of ingredients prescribed by a given recipe. The menu items were then grouped into menu item classes, which were the major components of the menu such as the main course or dessert.

Since any menu item chosen by the local school district food service staff was assumed to be palatable, the menu planning function was to combine menu items according to constraints placed upon a TYPE A menu. However, even though each item was assumed to be eligible for selection, some items were more popular with the children than others and some items may be served with a greater frequency than others while still retaining their demand. Frequency of service can be expressed as the minimum and maximum interval between repetition of the same menu item. This frequency of service assured that menus did not exclude some items altogether and also assured that an item was not served so often that it lost its appeal with the children.

Description of the Menu Generation Program. Since the legal requirements of the TYPE A lunch dictated the constraints placed upon the menu classes as well as the menu classes themselves, the problem faced in computer-assisted menu planning for this application was to choose menu items satisfying the TYPE A specification listed earlier, which minimized the menu cost while, at the same time, satisfied the frequency of service constraint. The first step was to transform the existing list of acceptable food items into a recipe file containing for each food item: a) the average cost per serving, b) nutritional data, c) frequency of service data, d) precooked ingredient amounts per serving, e) menu item class, and f) information concerning any possible interdependencies upon other food items. These items were then combined into a menu using a dynamic programming model in which each menu class was considered a stage and the requirements for each stage were satisfied by the selection of a single menu item. A schematic diagram of this programming model has been shown in Figure #2. This diagram shows that the program merely goes from stage to stage consecutively picking the lowest cost item from each stage (menu class) consistent with the dietary constraints. The total cost of the menu is then the sum of the average cost of each menu item chosen for the entire menu. If $\bar{c}_{ij}$ were to be the cost of the jth menu item in the ith menu class, the objective function would be written as

$$Z_{min} = \sum_{i=1}^{5} c_{ij} ,$$

subject to nutritional and service frequency constraints.

The nutritional constraints for this program were established in accordance with the requirement which must be met to allow the lunch program to qualify for Federal subsidies in the form of commodities or grants-in-aid. (19) Therefore, the following nutritional criteria were used:

a) Serve a protein-rich food item daily;

b) Serve a food item which is a good source of Vitamin C daily;

c) Serve a food item which is a good source of Vitamin A twice a week;

d) Serve a food item which is a good source of iron as often as possible (interpreted as daily by the program);

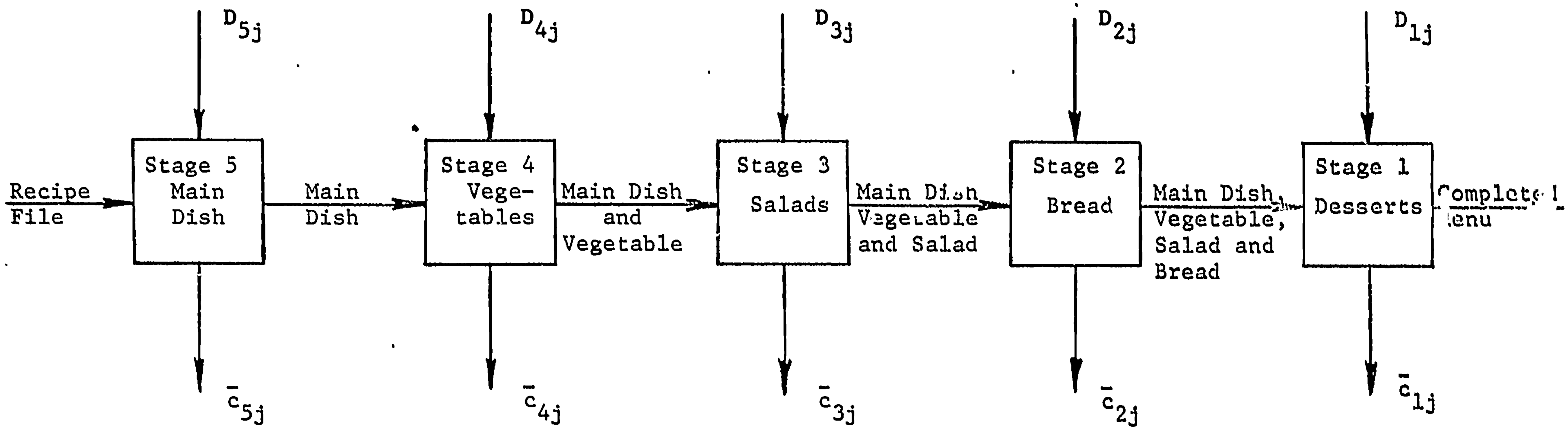
e) Serve a bread daily;

f) Serve butter or fortified oleomargarine daily;

g) Serve milk daily.

Since no decision is necessary in criteria f and g, these were not considered

FIGURE #2. SCHEMATIC REPRESENTATION OF DYNAMIC PROGRAM FOR SCHOOL LUNCH MENU GENERATION



where: D_{ij} = decision of jth food item of the ith menu class

$\bar{c}_{ij}$ = average cost of the jth food item of the ith menu class.

Objective Function $Z_{min} = \sum_{i=1}^{5} \bar{c}_{ij}$

as stages in the program, nor were their costs part of the minimization equation.

The program chose a minimum cost food item consistent with the frequency of service constraint at each of the following stages:

Stage 5 Main Dish
Stage 4 Vegetable or potato
Stage 3 Salad, fruit or other vegetable
Stage 2 Bread
Stage 1 Dessert.

The nutritional constraints were reduced to a binary number. The zero-one nature of such a number seemed appropriate since, under present operating policies, an item satisfies the nutritional constraint completely by equalling or exceeding the particular minimum nutritional level or it does not. No cumulative effect is recognized with respect to nutritional levels. The positions of the constraints in the basic binary number are shown below.

Bread	Salad	Iron	Vitamin C	Protein	Vitamin A
0	0	0	0	0	0

Each menu item was coded according to whether it satisfied one or more of these constraints, and a one replaced the zero where the constraint was satisfied. For example, cabbage carrot salad was coded as 010101. which showed that it satisfied the salad, Vitamin C and Vitamin A constraints.

In developing a menu the binary number 000000. was introduced as an input into the first stage. As a menu item was added at each stage, the zeros were changed to ones according to which constraints were satisfied. The final state variable (binary number) for the entire menu leaving the last stage was equal to 111111. twice a week and at least 111110. the rest of the week. Since the difference was the Vitamin A constraint which must be satisfied biweekly, a menu satisfying this constraint was forced into the selection process on Wednesday and Friday if this constraint had not been satisfied earlier. Since it was possible to satisfy a nutritional constraint more than once depending upon the particular choice of lowest cost foods chosen, the function that was used to transform the stage input to the stage output for a given decision was an "or" type function. This function allowed redundancy in the selection process. Allowing a constraint to be satisfied "at least once" seemed to be permissible considering the lack of specification for definite nutritional quantities and the goal of minimizing the menu cost.

The program was also written to allow for interdependencies of food items. An example of interdependencies among menu classes occurs when hamburgers are served. By specifying hamburgers as the main dish, the bread and salad constraints were also satisfied, since the hamburgers were served on a bun with a "hamburger salad" garnish. Therefore, the hamburger main dish, once specified, satisfied four of the six constraints, leaving only the two vitamin constraints to be provided by other items on the menu. Another reason for allowing interdependencies of food items between menu classes was the problem of menu item compatibility. Computers are now capable of planning well-balanced, low-cost menu plans; however, these menus are not always composed of combinations of menu items which are mutually compatible with respect to some relative measure of preference. This measure of preference was not the absolute one incorporated in the dislike cycle which allowed an item to be picked once per so many days. Rather, the relative measure of preferredness considered the mutual compatibility of menu items as a result of ingredients, color, texture, and so forth. For example, a menu generated during one of the simulations which was considered unacceptable was

Red enchiladas
French fried potatoes
Fruit cup
Corn bread
Cinnamon rolls.

Since the enchiladas are not made with an enriched flour, a bread is necessary. The cinnamon roll is a popular dessert and French fried potatoes are an equally popular vegetable. However, combined on a single menu, the starch content would turn the children into something resembling Sumo wrestlers before too long. Another example of an undesirable combination would be a daily sequence of similar items, for example, "... meat balls with spaghetti on Monday and beef patties on Tuesday." (19, p. 10)

However, if one were to attempt to classify all of the menu items which proved to be incompatible, then "(d)ata of this magnitude would be combinatorially impossible to obtain." (3, p. 23) Nevertheless, in a step-wise program such as the one used here, it is possible to use an heuristic program to block future selection of combinations which prove incompatible. It was felt that an heuristic program should be imbedded in the main program to "learn" the basic incompatibilities as specified during the operation and simulation activities. While such an inclusion was not of a trivial nature and increased the computer time per menu during the operation of the program, the nature of the application was such that the additional expense was felt to be justified for two reasons. First, the program was designed to be as foolproof as possible since the menus generated were to be used as the basis for the purchasing and inventory control model. Every time a poor menu is manually eliminated after being generated by the computer, this elimination upsets the frequency of service cycle in the computer for the eliminated items. Therefore, the entire program should be rerun without producing the offending menu. This would result in a more time consuming process than the addition of the heuristic program. Second, this program is to be used by operating personnel, many of whom are both skeptical of computerization and fearful for their jobs. If the computer program provided a poor menu and then repeated this menu frequently, operating personnel could easily begin to distrust any output which might be derived.

Implementation of the Program. The actual application of the program to an operating school system was not too difficult if one accepted the usual implementation and debugging problems as standard. Since any output of a program is only as good as the data used in the program, the first task was to obtain complete information on the various food items in each menu class. The food costs were based on average raw material cost per finished serving of a food item as actually used that year. It would have been much more meaningful to have had the total cost of any item, including labor and overhead, so that choices could have been made using prepared, semi-prepared, or raw ingredients depending upon the cost minimization program to choose the correct item. In this way the staff could see whether or not frozen, prepared French fries were a better buy than raw potatoes. However, labor and overhead costs were not available.

The "dislike" or frequency of service cycles should be identified through careful studies of the food demand cycles as well as the correlation between various food items on the menu and the effect of variations in associated menu items upon the demand of any one item. However, since this would require a detailed study in itself, the frequency of service cycles were obtained through subjective estimates by cafeteria personnel. After an item was chosen by the computer for a menu, it was given a very high cost ($100,000 per serving) until it had been out of circulation long enough to be eligible to be chosen again. Therefore, if for some reason such a menu item was considered while it was being cycled, it would be rejected due to its high cost or it would cause the menu cost to be so expensive as to attract immediate attention. In one of the early simulations such an occurrence took place because the "dislike" cycle for the breads was set so long that all of the breads were on the out-of-service cycle. Since the program was required to serve a bread, it chose the one from the out-of-service rotation at the cost of $100,000 per serving. This value caused the menu cost to exceed the output format immediately calling attention to the error. More bread choices were added to the recipe file, a much superior alternative to arbitrarily shortening the frequency of service cycle, and the program was run again.

The program was intended to be run each month for a typical school system. It would be no problem to generate as many menus as one desired. However, practically speaking, the schools generally receive Federally subsidized commodities once a month, the price of food fluctuates from day to day, and many supplies are perishable, so that long-range projections do not always serve a useful purpose. Thus, only a month's menu would be generated at a time. Since at the end of any time period a number of food items are cycling in their out-of-service phase, information to this effect must be recorded so that the same menus, with slight variations due only to minor price fluctuations, do not appear on the same day each month. Therefore, price and cycle information for each menu item must be stored in some manner. In this particular case, it seemed most expedient to punch out cards at the end of each run relating to the time in cycle of each menu item. Therefore, the data deck each month would consist of the recipe file of food items with their appropriate menu class, costs, frequency of service cycle times, and nutritional data as well as the cards containing the pertinent item cycle information from the previous run. With this information a monthly set of menus could be produced and the information for inventory control and purchasing to be discussed later would also be generated.

For comparative purposes, a set of ten monthly menus with twenty days per month was produced. These particular menus were based upon current average serving costs with only beans, dried peas, orange juice, and a few fruits considered as free commodities. No attempt was made to have specific menus on specific dates. The Federal menu planning guide states "(d)o not use the same food on the same day of each week. Every Monday should not be 'bean' day nor Tuesday 'meat loaf and green pea' day." (19, p. 10) A typical set of menus is shown in Figure #3. While these menus might not suit everyone's taste, they are representative of the menus now served and they satisfy the requirements for a TYPE A lunch.

Comparing the computer-generated menus for one year to those actually used in a school system, several things become evident. First, even though the number of main dishes in the recipe file selected for service was identical, the computer-generated menu showed a higher occurrence for each possible main dish, rather than concentrating on one or two favorites and slighting the other possibilities. For example, hamburgers were actually served twenty-one percent of the time while the computer selected these only fourteen percent of the time.

FIGURE #3. TYPICAL MONTHLY COMPUTER GENERATED MENUS*

1, Friday

Cowpuncher Beans	$ .0000
Carrots	.0170
Pear Half	.0000
Yeast Rolls	.0010
Raisin Pie	.0020
Total Cost is	$.0200

4, Monday

Beef Ravioli	$ .0310
Beets	.0210
Orange Juice	.0000
Corn Bread	.0020
Peanut Butter Bars	.0030
Total Cost is	$.0570

5, Tuesday

Weiners	$ .0536
Peas	.0250
Apricots	.0000
French Bread	.0010
Cinnamon Rolls	.0040
Total Cost is	$.0836

6, Wednesday

Fish	$ .0564
Green Beans	.0240
Cabbage Carrot Slaw	.0080
Deluxe Roll	.0020
Oatmeal Cookies	.0050
Total Cost is	$.0954

7, Thursday

Salisbury Steak	$ .0570
Whole Kernel Corn	.0280
Cabbage Carrot Salad	.0090
Yeast Rolls	.0010
Banana Cake	.0070
Total Cost is	$.1020

8, Friday

Country Fried Steak	$ .0600
Tomatoes	.0300
Carrot, Celery, Raisin Salad	.0090
Rolled Wheat	.0010
Brownies	.0090
Total Cost is	$.1090

11, Monday

Barbeque Meat	$ .0600
Broccoli	.0340
Mixed Salad Greens	.0090
French Bread	.0010
Applesauce Cake	.0110
Total Cost is	$.1150

12, Tuesday

Tacos	$ .0670
Peas	.0250
Green Salad	.0110
Corn Bread	.0020
Apples	.0110
Total Cost is	$.1160

13, Wednesday

Beef Chunks	$ .0690
Potato Flakes	.0500
Tossed Green Salad	.0110
Yeast Rolls	.0010
Coconut Bars	.0110
Total Cost is	$.1420

14, Thursday

Tuna	$ .0780
Green Beans	.0240
Green Vegetable Mixed Salad	.0110
Deluxe Roll	.0020
Prune Cake	.0110
Total Cost is	$.1260

15, Friday

Beef and Noodles	$ .0780
Whole Kernel Corn	.0280
Fruit Cup	.0140
French Bread	.0010
Chocolate Cake	.0130
Total Cost is	$.1340

18, Monday

Tamales	$ .0817
Carrots	.0170
Lettuce Tomato Salad	.0180
Corn Bread	.0020
Peach Cobbler	.0160
Total Cost is	$.1347

19, Tuesday

Stew Meat	$ .0860
Mashed Potatoes	.0500
Orange Juice	.0000
Yeast Rolls	.0010
Peanut Butter Bars	.0030
Total Cost is	$.1400

20, Wednesday

Hamburger on Bun	$ .1020
French Fried Potatoes	.0500
Whipped Jello Dessert	.0190
Total Cost is	$.1710

21, Thursday

Meat Loaf	$ .0980
Beans	.0800
Waldorf Salad	.0220
French Bread	$ .0010
Oatmeal Cookies	.0050
Total Cost is	$.2060

22, Friday

Roast Beef	$ .0860
Green Beans	.0240
Cole Slaw with Pineapple	.0220
Rolled Wheat	.0010
Applesauce Cake	.0110
Total Cost is	$.1440

25, Monday

Baked Tuna and Macaroni	$ .0900
Whole Kernel Corn	.0280
Carrot, Celery, Raisin Salad	.0090
Yeast Rolls	.0010
Brownies	.0090
Total Cost is	$.1370

26, Tuesday

Wiener on Bun	$ .0933
Tomatoes	.0300
Red Jello Fruit Salad	.0250
Chocolate Cake	.0130
Total Cost is	$.1613

27, Wednesday

Chicken and Noodles	$ .1000
Green Beans	.0240
Green Vegetable Mixed Salad	.0110
Rolled Wheat	.0010
Apple Goody	.0310
Total Cost is	$.1670

28, Thursday

Hamburger on Bun	$ .1020
Dried Peas	.0800
Pineapple Upside Down Cake	.0230
Total Cost is	$.2050

29, Friday

Combination Plate	$ .0980
Potato Flakes	.0500
Tossed Green Salad	.0110
French Bread	.0010
Milk Nickel	.0250
Total Cost is	$.1850

*Those items shown with a cost of $.0000 have traditionally been supplied as free commodities by the Federal Government.

While the high actual percentage results from serving hamburgers at least once a week, such a policy violates the Federal and State recommendations of using the school lunch as a learning experience by serving as great a variety of foods as possible. Also, serving such an item with that frequency tends to increase the lunch program cost to satisfy real or imagined popular demand for a food item. Hamburgers should not be served once a week if minimum costs are to be obtained.

Second, the computer-generated menus have less price fluctuation than those menus now in use. The variance from the average menu cost was reduced sixteen percent. This reduction is to be expected since the computer will always pick the lowest cost, compatible combination of foods to go with a high-cost main dish.

Third, the average cost per serving is reduced by approximately ten percent using comparable prices. The price structure is quite important, for the cost per serving actually recorded last year was 0.7 cents less than the computer-generated menu cost because of the use of free Federally furnished food. The savings by CAMP (Computer-Assisted Menu Planning, 3) would amount to almost $21,000 per year or the price of four teachers. While revenue from the school lunch program cannot be used to defray non-lunch related expenses, including those related to supervision of students within the cafeteria, revenues could be used to either upgrade the quality of the menus or to provide lunches for those children who are unable to pay the full cost of the lunch, an expense otherwise borne by the taxpayers. Since the school menus seem to have been planned skillfully for a number of years, this might account for the smaller savings attributal to computer-assisted menu planning than those reported by some authors. (10) However, an average cost per serving of 14.36 cents is less than what the cost would have been for the public schools had they not received quantities of free meat and poultry.* If these free food stuffs were eliminated--the milk subsidy was reduced this year, for example--as some speculate it might be, it would probably be much more difficult for human menu planners to adjust their food combinations for minimum cost menus under new price constraints than it would be for the computer to adjust to this new environment.

Finally, the real power of the Computer-Assisted Menu Planning is in the ability of the decision-maker to simulate possible outcomes given a changing set of inputs and use these simulations as control mechanisms for his entire operation. Thus, integrating CAMP into an inventory control program, as is done in the following section, would free the decision-maker from much of the tedious clerical work associated with present operations. The burden of actual "managing" of inventory control, ordering and menu planning could be accomplished by the computer, freeing the manager to use his creative initiative to do work at which humans excel.

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*Not included in this average cost per serving is the cost of milk at $.0264 per serving ($.0624 less $.036 Federal Subsidy) and the cost of other edible and non-edible items associated with the typical school lunch.

The average cost per serving including milk would be approximately seventeen cents, or less than fifty percent of the price charged for food. This violates the State recommendation which states that a minimum of sixty percent of the total income should be used for the purchase of food. (15, p. 1) Therefore, if this recommendation were to be followed, more expensive menu items should be included in the recipe file. Also, since the lunch program is now operated either without profit or at a loss, one might infer that labor costs exceed the recommended thirty-five percent maximum of total income. (15) This inference can be verified, which points up the need for a study into the operation of the cafeterias themselves.

COMPUTERIZED INVENTORY CONTROL

Food Demand Forecast Model. After generating an acceptable set of menus for a particular month based upon the current bid prices of each menu item, the amount of food to be purchased as well as the optimal ordering quantity and interval must be determined. The amount of each menu item to be purchased was obtained through a food demand forecast model. This model had the capability to predict the quantity demanded for its menu item as a function of the date. (7, pp. 105-110) The entire food demand for the month was then a compilation of all menu item forecasts for the month.

The first step in formulating the model for a particular item was to obtain the historical pattern of demand. This demand pattern suggested a time-dependent forecast model of the general form

$$X_{it} = a_1 + a_2 t + a_3 \sin \omega t + a_4 \cos \omega t + a_5 \sin 2\,\omega t + a_6 \cos 2\,\omega t,$$

where a_1 = level of demand

a_2 = trend of demand

a_3, a_4, a_5, a_6 = amplitude and $\omega =$ phase angle of seasonal variations

X_{it} = forecast of the quantity of the ith food item for the tth month in the future.

As an example, the data for enchiladas were used in this model and the coefficients were obtained from these data as found in Figure #4. the demand for enchiladas F(TIME) and the time, from September 1, 1.000 to May 22, 9.735, were reduced by a least squares method of curve fitting to the coefficients shown in the lower line of figure #4. An illustration of the curves obtained from these coefficients for two typical main dishes, enchiladas and hamburgers, may be seen in Figure #5. While it was possible to use one curve for a number

FIGURE #4. FOOD DEMAND FUNCTION DATA AND COEFFICIENTS--ENCHILADAS

TIME

1.300	1.535	2.233	3.367	4.060	4.300
5.434	5.765	5.900	6.100	6.765	7.060
7.332	7.466	7.700	8.000	8.466	8.935
9.060	9.165	9.735			

F(TIME)

873.000	898.000	916.000	903.000	877.000	919.000
889.000	890.000	873.000	861.000	905.000	820.000
809.000	800.000	846.000	907.000	904.000	902.000
851.000	860.000	916.000			

CO-VARIANCE MATRIX

1.203844	-0.213799	-0.518276	0.366608	-0.022112	0.367121
-0.213799	0.039807	0.101170	-0.071574	0.002803	-0.069264
-0.518276	0.101170	0.374961	-0.188370	-0.014172	-0.208718
0.366608	-0.071574	-0.188370	0.233439	0.009837	0.110694
-0.022112	0.002803	-0.014172	0.009837	0.096989	0.004707
0.367121	-0.069264	-0.208718	0.110694	0.004707	0.232407

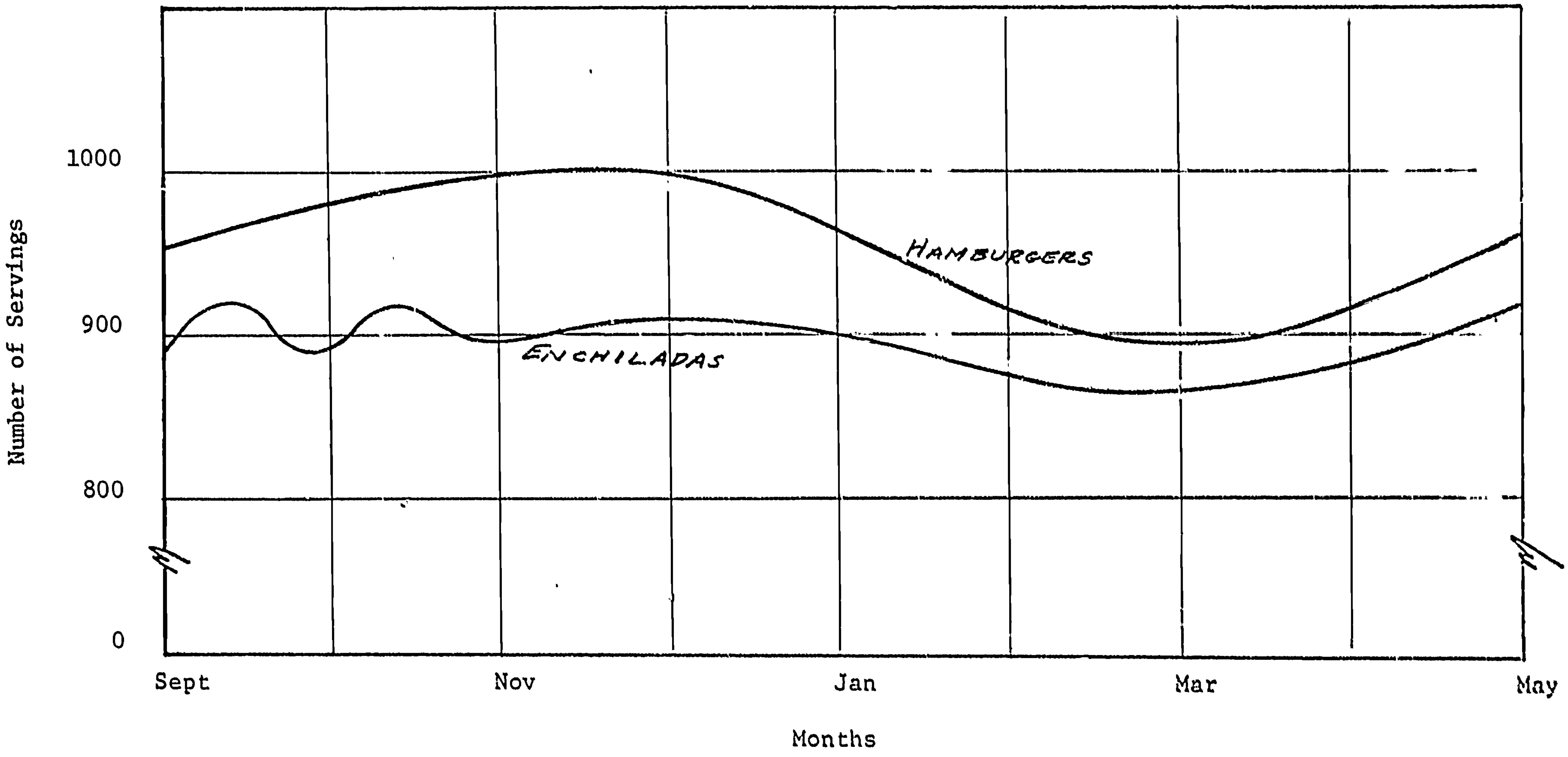
DATA VECTOR

18419.003	113283.843	-3485.215	2808.881	198.135	217.653

COEFFICIENTS

A1	A2	A3	A4	A5	A6
865.153	3.374	30.650	-17.368	7.610	5.338

FIGURE #5. GRAPH OF FOOD DEMAND FORECAST MODEL



of menu items due to the apparent similarity of demand patterns, hamburgers and fish for example, Figure #5 does illustrate the differing characteristics of food demand encountered in this study. It was observed that not all of the terms obtained for each group of menu items, where a group was defined as those items having similar demand characteristics within a prescribed significance level, seemed significant. However, if a term was not significant, its coefficient would be so small as to have a negligible effect upon the final demand prediction.

After verifying the validity of the models as predictors of food demand, a periodic updating routine was established so that the models reflected any current trends in food demands. This updating used a method of exponential smoothing, often referred to in references on inventory control (7, p. 135), which heavily weights current data while giving little credence to a point of extreme deviation Finally, due to the lack of any definitive information on the demand of menu items in menu classes other than the main dish, all food demand forecasts were based upon the number of servings predicted for the main dish.

Inventory Control Models. After calculating the predicted demand for each menu item to be served in a particular month, the next problem was to develop a method for controlling the ingredient inventories. Much work has been done in the field of inventory control and for this reason many models are already available. With respect to the available models dealing with known demands, models have been developed for both continuous and discrete functions. The items exhibiting relatively continuous and constant demand, as exemplified by ground meat, napkins, and so forth, can be controlled by the traditional Economic Ordering Quantity (EOQ) formulas. (8, p. 202) While further study is still warranted to determine the groups of ingredients whose demand and cost characteristics satisfy the underlying assumptions of this model, several groups of ingredients seemed particularly suited to this treatment.

The items exhibiting a discrete demand function, as exemplified by tortillas, chicken, and so forth, were found to be best represented by a dynamic programming model as suggested by Bellman (5) and Starr (16). Similar to the menu generation model, the minimum cost for each combination of purchase decisions available at that stage was calculated beginning at stage one. This minimum cost value was carried forward to stage two to be used as one of the inputs to that stage. The minimum cost at stage two was then calculated considering all inputs to that stage. This process was continued for N stages, providing the optimal decision at any particular stage. Thus, the basic cost equation could be written

$$\text{Total Cost at Stage } k = [(\text{Purchase Cost}) + (\text{Inventory Cost}) \times (\text{Inventory carried forward}) + (\text{Cost of Previous Stage})]$$

This method greatly reduced the number of calculations involved since only the optimum results were carried forward. The optimal decision policy has the property that whatever the initial condition was the remaining decisions must constitute an optimal policy with respect to the state resulting from the first decision.

An example of the use of this discrete model for tortillas is found in Figure #6. Assuming that the average cost of holding a package of one dozen tortillas is $0.02 per week, the purchasing cost is $15. per order, and the requirements per week as determined by the menu generator are as shown, the optimal purchasing policy for any stage is provided by the dynamic programming model. As an illustration of the interpretation of this result, to

FIGURE #6. OPTIMAL INVENTORY POLICY—TORTILLAS

Inventory Cost = $ 0.20 per week per unit
Purchasing Cost = $15.00 per order

Period 1 Requirement = 0.
Period 2 Requirement = 650.
Period 3 Requirement = 0.
Period 4 Requirement = 650.
Period 5 Requirement = 650.
Period 6 Requirement = 0.
Period 7 Requirement = 1300.
Period 8 Requirement = 650.
Period 9 Requirement = 650.
Period 10 Requirement = 0.
Period 11 Requirement = 650.
Period 12 Requirement = 650.
Period 13 Requirement = 0.

Optimal Policy at stage 1 minimum cost = $ 0.00
Purchase 0. units in period 1

Optimal Policy at stage 2 minimum cost = $ 15.00
Purchase 650. units in period 2

Optimal Policy at stage 3 minimum cost = $ 15.00
Purchase 650. units in period 2

Optimal Policy at stage 4 minimum cost = $ 30.00
Purchase 650. units in period 4
Purchase 650. units in period 2

Optimal Policy at stage 5 minimum cost = $ 43.00
Purchase 1300. units in period 4
Purchase 650. units in period 2

Optimal Policy at stage 6 minimum cost = $ 43.00
Purchase 1300. units in period 4
Purchase 650. units in period 2

Optimal Policy at stage 7 minimum cost = $ 58.00
Purchase 1300. units in period 7
Purchase 1300. units in period 4
Purchase 650. units in period 2

```
Optimal Policy at stage 8 minimum cost  = $  71.00
Purchase  1950. units in period 7
Purchase  1300. units in period 4
Purchase   650. units in period 2

Optimal Policy at stage 9 minimum cost  = $  86.00
Purchase   650. units in period 9
Purchase  1950. units in period 7
Purchase  1300. units in period 4
Purchase   650. units in period 2

Optimal Policy at stage 10 minimum cost = $  86.00
Purchase   650. units in period 9
Purchase  1950. units in period 7
Purchase  1300. units in period 4
Purchase   650. units in period 2

Optimal Policy at stage 11 minimum cost = $ 101.00
Purchase   650. units in period 11
Purchase   650. units in period 9
Purchase  1950. units in period 7
Purchase  1300. units in period 4
Purchase   650. units in period 2

Optimal Policy at stage 12 minimum cost = $ 114.00
Purchase  1300. units in period 11
Purchase   650. units in period 9
Purchase  1950. units in period 7
Purchase  1300. units in period 4
Purchase   650. units in period 2

Optimal Policy at stage 13 minimum cost = $ 114.00
Purchase  1300. units in period 11
Purchase   650. units in period 9
Purchase  1950. units in period 7
Purchase  1300. units in period 4
Purchase   650. units in period 2
```

minimize the inventory cost of tortillas for the three month period, the output at stage thirteen shows that 650 packages should be delivered the first week, and 1300 packages per order should be delivered in weeks four, seven, eight, and eleven. This policy would result in a quarterly inventory cost for tortillas of $114.00 The importance of using a model which is representative of the true situation is illustrated by the fact that if the EOQ formula had been used to determine the purchasing policy the resulting cost would have been $214 or an increase of 88 percent.

One limitation encountered in this study should be emphasized. Since the success of using this model relies upon the values of the costs substituted into the formulas, accurate determination of these costs is critical. Adequate data were not available to provide the desired validity of the optimal policy, especially with respect to the cost of holding an item of inventory. This holding cost should include such items of cost as storage, handling, damage, spoilage, insurance, and so forth. Since these costs were unavailable, estimates were made using the study team's best engineering judgment applied to what data were available.

Finally, an additional function could be performed by these models after stabilizing inventories. This task would be to generate quarterly bid forms and purchase orders. To accomplish this task, the menus for three months would be simulated and the demand for the ingredients would be predicted. Then the ingredients with their appropriate minimum and anticipated order quantities would be printed out on "bid request forms" by the computer. After obtaining and approving the quotations, the approved prices would be entered in the menu generator along with Federal commodity information and a minimum cost set of menus would be produced a month at a time. From these menus and the inventory models, purchase orders would be produced for each supplier. In this way the clerical burden on the lunch program staff would be reduced while lowering the cost of the entire program.

CONCLUSIONS

This study was intended as an example of how operations research could be applied in one segment of public school administration, the school lunch program. A computer-assisted menu planner was developed which generated a monthly set of menus satisfying the nutritional constraints and food service cycles while eliminating unacceptable menus. This technique also reduced the menu cost by six percent.

The menu generator was then combined with a set of inventory models to determine the ordering quantities and ordering intervals which would result in the minimum cost policy for inventory control. The dynamic programming techniques used to develop the models in this study were chosen for their applicability for the type of cost and demand data available both now and in the future. Even with the data available, substantial savings have been shown to be possible through the use of these models both in reduction of direct costs and in reduction of clerical effort

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