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Data Structures for Integrating Quality and Cost Factors in a Foodservice Operation

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ABSTRACT

The information requirements for proper management of product quality and safety in a foodservice call for organization and manipulation of large amounts of data. This requires a structural organization to the data, which has large capacity while simultaneously being flexible enough to rapidly deliver information developed from the data. A matrix data structure meets these requirements and conveniently integrates new procedures and new products into a well-structured management information system. Such a structure is a convenient computational device, especially when implemented on a computer, and can be used for immediate feedback of information to the manager. Product quality and safety management requires that these functions be integrated into such a system and related to cost. Only in this way will the resource utilization impact of these control functions on the overall foodservice operation be apparent. Although in this paper the data structures are applied to foodservice operations, other applications are possible. In particular, dairy processing operations, meat and other food processing operations as well as food distribution systems, could all benefit from applications of such structures.

The present generation of foodservice managers has not been adequately prepared, either through education or experience, for the demands imposed by the political, economic and technological environment surrounding the foodservice industry today. The intensity of these demands is increasing and their impact on the decisions made by foodservice managers will be even greater in the decade to come. It is in this setting that the manager must protect the quality of the menu items he serves and also guarantee that the food is safe to consume.

To protect food quality and insure food safety, while simultaneously meeting production requirements, cost constraints and labor management restrictions, requires that the manager integrate a large set of information into decision making. A difficult task required for decision-making is for the foodservice manager to rapidly obtain current information about each menu item that is produced and served. To work for the foodservice manager, all this information must be rapidly stored, retrieved, *integrated*, distributed and displayed. This paper is not intended to be a report of a scientific investigation, but describes the need for development of and potential use of data structures to perform these functions.

CHARACTERISTICS OF THE FOODSERVICE INDUSTRY

Planning for procurement, production, assembly, distribution and service of menu items is the most important task faced by foodservice managers. This task involves management of the daily activities of foodservice personnel to ensure that menu items are microbiologically safe, nutritious, of acceptable sensory quality and within budgeted costs.

Perhaps because meals are such an ordinary phenomenon, the complexity of foodservice is not fully appreciated by those not trying to solve its problems. Hospitals and nursing homes, for example, serve a minimum of three meals a day and operate an average of 14-15 h daily for 7 days of the week. The assembly, delivery and service of meals to patients are handled by different teams of workers who may be part-time, unskilled, often young high school or college age people who usually leave the job in less than 1 year (*5*).

In health care facilities, meals are served to the same individuals over longer periods, making a variety of menu items necessary. Long-term patients in hospitals and nursing homes who have different social-cultural backgrounds and diet requirements, increase the need for both variety and special modification of menu items. Ruf (*6*) counted the number of menu items from a complete set of patient, cafeteria and coffee shop menus and production sheets for the same day of the week in 25 hospitals in southern California. She reported that the total number ranged from 116 to 425. The average number of menu items prepared and served daily was 231. Because of the complexity of the foodservice operation--mainly due to the many different types of menu items produced in small quantities--anticipating the impact of decisions on the interrelated components of the foodservice is difficult. Protecting food quality and insuring food safety are two of many requirements of the manager. To achieve the organization's goals regarding these requirements means that quality control and quality management information must be integrated into the bigger information system for the foodservice.

FOODSERVICE OPERATIONS

All foodservices are in the business of converting materials (ingredients) into finished goods (menu items) and serving these menu items to a customer. Thus a foodservice operation has a manufacturing component and a service component. The foodservice has the special problem that the ingredients and the finished products are perishable. In this setting, innocuous-appearing changes can have subsequent effects which are unpleasant for the manager. Changing prices of ingredients, changing documentation requirements, changing labor requirements or even changing a menu item in today's noon meal can have important consequences which at the time of the change are very difficult to determine. Other important information must be integrated into a system for the manager to document the performance of the foodservice. In health care applications, it is important to know the nutrients served to the patient via the menu items and to keep running totals over time for each patient for many nutrients served. The nutrient delivery impact of menu changes or of ingredient substitutions must be made available to the manager of a foodservice operation. This information should be considered in planning substitutions and be available to clinical dietitians, as well.

The essential requirement of the information processing system designed for a foodservice is that it integrate the various functions of the foodservice, so that the interactive effects of the components on each other are taken into account. The system must be able to deal with a large number of products and must provide information to the foodservice manager in a timely fashion. Ideally, the system should be structured to help the manager anticipate the impact of internal or external changes and should allow the manager to test proposed solutions to problems of the foodservice.

A MATRIX STRUCTURE FOR A FOODSERVICE

A matrix is a rectangular array of objects (7)--usually numbers--in which the position of the entry in the matrix gives the entry meaning as well as the identity (value) of the entry. When properly matched, matrices are algebraic objects which can be multiplied, to yield new matrices whose entries can give useful information. The structure proposed for the foodservice management information system involves several matrices which are multiplied together. The focus of the system is the resource utilization pattern and cost of production and service for one serving of each of the potential menu items of the foodservice. To understand the meaning of the matrix products used in this development, it is important to understand how the matrix multiplication is carried out. This may be found in the appendix for those unfamiliar with the topic.

One important matrix in the structure relates the menu items to the resources of the foodservice required to produce and serve them. In this instance, each row of the matrix corresponds to one of the menu items and each column corresponds to one of the resources (ingredients, labor time, machine time, overhead, nutrients) used in the production and service of the menu item. The entry in the ith row jth column will give the amount of resource j required to produce one serving of menu item i. An example of how portions of such a matrix might look in a given application is shown in Table 1. We denote this matrix with the letter R.

The next matrix we construct can take several guises, but to illustrate we put it in its forecasting role. Its entries relate the menu items to the time period or meal in which they are served. Each row in this matrix corresponds to a demand period for the foodservice. In a traditional foodservice, each row could correspond to one meal (breakfast, dinner, supper, snack) in the menu plan. (In a more amorphous situation, each row could correspond to a fixed time period --11:00-11:30 a.m., for example.) Each column of the matrix corresponds to one of the menu items which the foodservice can produce. The

TABLE 1. *A section of the technological matrix R.*

		Resources inputs				
Item		Sour cream 147	Butter 148	Peas-canned 149	Electricity 150	Quality control labor 151
	.	.	.	.	.	.
	.	.	.	.	.	.
	.	.	.	.	.	.
Cucumber/sour cream	83.	...1.2	0	0	0	3.39...
Buttered peas	84.	...0	.17	.5	.03	.26...
Bread dressing	85.	...0	.8	0	.01	.52...
Au gratin potatoes	86.	...0	.02	0	.08	3.13...
Baked potato/sour cream	87.	... .75	0	0	.12	.26...
	.	.	.	.	.	.
	.	.	.	.	.	.
	.	.	.	.	.	.

TABLE 2. *A section of the forecasting matrix S.*

		Menu items				
		Cucumber/ sour cream 83	Buttered peas 84	Bread dressing 85	Au gratin potatoes 86	Baked potato/ Sour cream 87...
	.	.	.	.	.	.
	.	.	.	.	.	.
	.	.	.	.	.	.
Meal numbers	16	0	0	0	0	0...
	17	210	0	0	0	0...
(or Demand period)	18	0	255	0	150	0...
	19	0	0	215	0	230...
	20	0	0	0	0	0...
	21	0	0	170	0	80...
		.	.	.	.	.
		.	.	.	.	.
		.	.	.	.	.

entry at the intersection of the ith row and jth column in this matrix is the anticipated demand for menu item j in demand period i. See Table 2 for an example of this forecasting matrix. We shall denote this matrix with the letter S.

The last matrix necessary for this application is a matrix with exactly one column. The ith entry in this column will correspond to the price per unit of the ith resource of the foodservice. See Table 3 for an example of this matrix. We will denote this matrix with the letter P.

To generate useful information we must multiply the three matrices (Table 4) together, the resulting product we denote with the letter C.

$$S \times R \times P = C$$

TABLE 3. *A section of the price matrix P.*

Item	Resource inputs	Price per unit
	.	.
	.	.
	.	.
Sour cream	147	.056
Butter	148	.013
Peas - canned	149	.171
Electricity	150	.056
Quality control labor	151	.052
	.	.
	.	.
	.	.

INTERPRETING THE MATRIX STRUCTURE

On the surface, it appears that the only information generated by this process is embodied in the matrix C. This is not true, but the matrix C does contain important information about foodservice operations. If we consider

TABLE 4. *The cost per meal matrix C.*

	Meal number	Cost ($) per meal
	.	.
	.	.
	.	.
$S \times R \times P = C =$	16	187.23
	17	431.92
	18	651.37
	19	600.09
	20	149.50
	21	210.31
	.	.
	.	.
	.	.

the ith entry (matrix C consists of one column), it is the cost of operating the foodservice during period i if the forecasted demand for menu items is correct. This structure then organizes all the information necessary to provide this cost amount for the foodservice manager.

To get more information from this structure requires that some of the factors determining the values in C be analyzed separately. Particularly if we look at the product $S \times R$ we can determine many meaningful things about the use of foodservice resources during the time periods chosen in the construction of matrix S. The entries in the $S \times R$ matrix are determined by multiplying the forecasted demand for menu items for a particular time period, times the amount of each resource required for a serving of those menu items. For a given meal or time period, the entry in the matrix indicates the amount of each resource used to serve that meal.

So if the entry at the ith row jth column is analyzed, it gives the amount of resource j used to serve meal i. (Recall that resources include labor, machine time, etc. as well as ingredients.) Other information can be garnered by summing the entries in the product matrix columns. If a particular resource is called 2% milk, the sum of the column entries corresponding to this label will give the amount of 2% milk used by the foodservice over the planning horizon (menu cycle). This information can be used to project order quantities over a future planning period, or to monitor and control inventory levels. If the column is summed for consecutive meals in the planning period, the result will be the forecasted use of a resource for those meals. For items which must be replenished on a short-term basis, this will generate the order quantities in a straightforward way. Important information is also embedded in the R × P portion of the overall matrix product S × R× P. The R × P matrix is a single column in which each entry corresponds to the cost per serving of a particular menu item. More information can be developed by performing special operations on these matrices, see (*2,3,4*) for examples.

NUTRIENT AND FOOD SAFETY INFORMATION

Much of the information developed through the matrix structure will depend on the kinds of categories chosen for the columns of the R matrix. If the user is interested in monitoring nutrient delivery, for example, the nutrients must be specified and the entries in each corresponding column of R will indicate how much of that nutrient is provided by serving a particular menu item. After the S × R product is performed, summing a column corresponding to a particular nutrient will give information about the delivery of that nutrient over the planning horizon. In a well-controlled service environment, such as a nursing home or hospital, each patient will have an S matrix, indicating the consumption pattern for that patient. The entire matrix product then can become a dietary monitoring and control device which can compare in an organized fashion, expected and actual food consumption information.

As in the nutrient example, developing food safety information for a menu item or a meal will depend upon the choice of categories for the columns of R by the user. In a particular application, resources used for insuring food safety might include managerial time, quality control time required from non-managerial staff (for performing tests, or taking measurements) or the use of special equipment. In such instances, the same analysis as above will indicate the value (cost) of the quality control resources expended over the planning horizon, or for any specified subset of the meals within the planning horizon. More specifically, the maintenance of sensory quality requires the labor time of individuals with this responsibility. The matrix R could be organized so that a separate column is devoted to each such individual. Other columns could correspond to other resources used in the sensory quality control effort. For a given menu plan, analysis of this section of the resulting product matrix would provide information about the cost and amounts of resources used to maintain adequate sensory quality.

IMPLICATIONS OF THE MATRIX STRUCTURE

All the calculations that have been discussed, although tedious and time-consuming to do, could be performed without the aid of a matrix. The key advantage of the matrix structure is organizational. With the structure in place, all the disparate resources of a foodservice can be treated the same for computational purposes. This allows the interactions of the various components of the foodservice to be portrayed through a single system, rather than having each treated separately. The structure can be used to help take the guesswork out of determining the impact of some actual or anticipated change. For example, the impact on labor requirements of eliminating a particular menu item or the impact on nutrient delivery of switching from whole milk to 2% milk could be portrayed through this structure.

Another advantage of the system is its flexibility. If there is a particular way in which the user wishes to view the foodservice's expenditure of resources, it is usually possible to construct the corresponding columns of the R matrix. Resource requirement columns can be created for labor types, for departments, for regulatory categories, as well as for ingredients and nutrients. Nor does one choice of column categories preclude the simultaneous computation of values for a different pattern of foodservice information, using the same matrix structure.

The most important input requirements for driving this model are the values of the R matrix. In some instances, determining these values is straightforward. The amount of a particular ingredient used to make one serving of a menu item is easily determined, for example. Determining the amount of unskilled labor required to make one serving of this menu item or the amount of thiamine it contains requires more effort on the part of the user. Other inputs include forecasted demand for menu items, and the price per unit of the resources expended in menu item production and service.

This structure has been tested in a prototype setting of a small nursing home foodservice. This particular operation had a 14-day planning horizon--56 meals--with 139 menu items requiring 194 ingredients and other resources for construction. The S matrix in this implementation was 56 rows by 139 columns (56 × 139), the R matrix was 139 × 194 and the product matrix--S × R was 56 × 194. Although these matrices are not as large as implementations in some other operations, this test showed that the computations could be carried out swiftly and that information was organized for quick retrieval of key facts and values.

Most of the information required to drive the matrix structure is already available to foodservice managers. Putting this information into a matrix format allows it to be manipulated and stored with ease. The structure is particularly suited to electronic computation, and will allow foodservice managers to have instant access to important information through programming a computer for interactive use. It is a feature of all foodservice implementations envisioned so far, that such a computer implementation could be accomplished with only modest storage requirements and with ordinary peripheral equipment. This aspect of the matrix product model should make this management control tool available to even the smallest foodservice operations. Finally, applications of this kind of structure can be made to other food processing and service operations, including dairy processing plants, as well as meat and vegetable processing and distribution systems.

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APPENDIX--MATRIX MULTIPLICATION [*1*]

If A and B are symbols for matrices, several special conditions must be met before it is possible to form the product AB. Suppose that A has n rows and m columns and that B has r rows and s columns. Typically A is said to be an n by m matrix, with B an r by s matrix. The product AB can only be formed if m = r -- the number of columns in the first matrix factor must equal the number of rows in the second matrix factor. If this condition is met, the product matrix will be an n by s matrix with entries determined by combining the rows of A with the columns of B in a special way. For convenience, let C = AB. The entries of the product matrix can be represented by $c_{i,j}$ -- the entry in the ith row, jth column. The formula for computing this entry is

$$c_{ij} = \Sigma\, a_{it} b_{tj}$$

Observe that this sum only requires entries from the *ith* row of A and the *jth* column from B. Since m = r, we know there are exactly enough entries in the *ith* row to match with the entries in the *jth* column of B.

Suppose

$$A = \begin{bmatrix} 2 & 3 & -1 & 2 \\ -2 & 5 & 4 & 7 \end{bmatrix} \quad \text{(2 by 4)}$$

$$B = \begin{bmatrix} 3 & 0 & 0 \\ 4 & 1 & 5 \\ -2 & 6 & 3 \\ 4 & 1 & 5 \end{bmatrix} \quad \text{(4 by 3)}$$

then C = AB so:

$$C = \begin{bmatrix} 28 & -1 & 22 \\ 34 & 36 & 72 \end{bmatrix} \quad \text{(2 by 3)}$$

for example:

$$c_{12} = \Sigma\, a_{1t} b_{t2} = 2 \bullet 0 + 3 \bullet 1 + (-1) \bullet 6 + 2 \bullet 1 = -1.$$

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