MANAGEMENT SCIENCES IN THE FOOD INDUSTRY - A STATUS REPORT

BY

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Management Sciences in the Food Industry

The program for this meeting has specified that this paper should survey the "state-of'the art" of applications of management science in the food industry and should emphasize recent developments in:

(1) the nature of problems attacked

(2) the general kind of techniques used.

A. Industry definition/Slide 1)

For the purpose of this presentation we shall define the food industry as one concerned with:

(1) Growing food products (Agriculture)

(2) Intermediate processing (livestock & livestock products)

(3) Final processing (Manufacturing)

(4) Consumption (Marketing and Distribution)

To describe the extent of management science activities, I had to rely primarily on published sources of information and focus only on those aspects that bear some direct relationships to food. The selected bibliography to which I refer in this talk does not cover articles in manufacturing, distribution and marketing which have a broader applicability. As one follows a product from its source to ultimate consumption, the unique identity of the food industry category vanishes and becomes merged with other industrial or management science activities/Slide 2/ and therefore, could easily lead to a talk which would encroach on topics assigned to other speakers at this conference.

As a further limitation on the scope of this paper, I have selected only references about the food industry published since 1960. Even though the enclosed bibliography has 114 items, it should not be construed as an attempt to assemble a definitive compilation of available references. This is a job yet to be done by a dedicated individual.

As is the case in all industrial Operations Research, most of the significant work has not been as yet published or, perhaps never will because of competitive considerations. Hence our discussion can serve only as the barest outline about activities as they may have taken place a few years ago.

B. <u>IMPORTANCE OF INDUSTRY</u> - U.S.A.

It would be appropriate to place the importance of the food industry into the proper economic context. In view of the difficulties involved in defining the scope of the food industry, it would seem that the INPUT-OUTPUT method of accounting for industry's contributions to the Gross National Product would be the easiest method. Results of the 1958 U.S. Commerce Department Study are now available (Ref. 35) and are explained in a relatively simple form by Leontief (Ref. 63). The input contribution of food-associated industrial classifications are shown on Slide 3 and indicate that the sum of outputs of food industry sectors of the USA economy, based on 1958 performance, accounts for 25% of the Gross National Product and hence ranks as the largest activity in our economy.[1] But this is only the U.S. picture, the importance of food in the world's most advanced industrial country.

1/ As a matter of interest: Wholesale & Retail trade ranks second with 126.3 billion; Real estate & rental third with 82.4 billions; motor vehicles & equipment fourth with 30.3 billion.

C. IMPORTANCE OF INDUSTRY - WORLD PICTURE

The startling fact about food consumption today is that over one half of the world's population has a calorie intake of less than 2250 calories/day[2] and that the average per capita food production in the world is actually declining (Ref. 24 and 82). Unless there is a change in many factors influencing the present trends, there is evidence that the percentage of the human population without adequate food supplies will increase with the next 20 years (Ref. 81 and 69). Even though the starving countries are now devoting 60-80% of their Gross National Product to food manufacturing (Ref. 98), it is clear (Ref. 9) that the road to increased food consumption is primarily through increased productivity in the entire food industry sector, from agriculture through distribution.

Contrary to popular notions, the leading performance of food industry as one of the most productive in the world is only of a relatively recent origin. Slide 4 focuses on significant trends in one sector of the food industry - agriculture. It is hoped that similar indexes will become available demonstrating the aggregate productivity of the food industry in the U. S. A. particularly in view of the fact that there has been a gradual decline in the real cost of food while the nutritional content and labor-saving aspects of food have been increasing.

2/ Defined as starvation level (Ref. 24).

Brown (Ref. 9) and Pawler (Ref. 82) discuss factors contributing to productivity of the food industry. They point out that a complex inter-action between literacy levels, capital inputs, credit availability, transportation services, fertilizer and insecticides, as well as a general marketing orientation of manufacturing and distribution must be present before desired efficiency can be attained. The remainder of this presentation will be devoted to specific contributions made by management sciences towards the identification of a better balance between conflicting input factors in the food industry.

D. Agriculture and the Economy

Inter-relationships between agricultural inputs and those of other sectors of the economy relate to issues of national planning and can be found in a few (Ref. 77 and 64) case studies. Mathematical programming techniques are involved in dealing with such a large number of economic factors. The work in the U.S.A. is mostly concerned with regional issues. For instance, Fox (Ref. 33) constructs a model relating prices with production and consumption levels of certain farm commodities in several different geographic regions. Similarly, Heady and Egbert (Ref. 41 and 42) study inter-regional competition and optimal crop production allocation in 122 producing regions. In both cases, linear programming techniques are used. Qualitative and statistical surveys of the overall industry provide us with further guidelines about areas which potentially could profit by the use of management science techniques. A summary analysis (Ref. 17) presents problems as seen from the standpoint of a less developed economy; French's discussion (Ref. 34) would be of interest as an introductory review - both papers contain good bibliographies. The work by Preston and Bell (Ref. 91) is useful primarily as a source of industrial data about changing sizes of firms involved in food processing and distribution.

E. Allocation of Resources to Agriculture

Considering the number and scope of published material in the area of resource allocation to farming, we can conclude that management sciences have a significant contribution to make in this area. A useful place to review accomplishments is in a state-of-the art paper by Heady (Ref. 40) containing an extensive bibliography. A broad review of applicable mathematical techniques can also be found in Ref. 70. The application of linear programming to viewing a farm on a system is extremely well developed by David (Ref. 18); his approach has a broad generality and examines crop inputs and outputs from a time-phased point of view while taking into consideration labor, livestock, fertilizer and other limitations. Linear programming is also the main theme of papers illustrating special problems such as increasing returns to scale (non-convexity) (Ref. 22); production planning for several large farms (Ref. 106) or several districts, (Ref. 78) or a single farm (Ref. 111). Regional planning is also treated in Ref. 58. Integer programming is illustrated in the form of several case studies in Ref. 20.

Resource allocation, with particular emphasis on capital investment planning, is solved in one case by mathematical programming methods, (Ref. 59) and in another by applying decision theory (Ref. 10).

Gaming theory is introduced in Ref. 74 and in a simulation form as a Farm Management Game (Ref. 21) wherein several teams compete to achieve highest profits by means of resources allocation to six types of crops, nine types of livestock, four types of land and call for decisions in purchasing, for livestock breeding and crop rotation.

F. Support to Agriculture

The relationship between the productivity of the food industry and other sectors of the economy is best illustrated by reviewing some of the operations research models applicable to technological inputs which support agriculture. For instance, farm machinery scheduling (Ref. 101) and the application of insecticides (Ref. 95, 113 and 114) show how efficiency in these functions can be analysed.

G. Crop, Pack and Harvest Planning

The relationship between acreage commitments, sowing sequence, decision-making while the harvest is taking place, evaluation of purchasing alternatives, etc. involves a large number of ill-defined problems where the uncertainty as to the outcome of the weather or prices calls for the application of sequential decision theory, simulation and gaming theory. It is, therefore, no surprise that one finds very little published material in this discipline except for References 14, 39 and 62. As large fruit and vegetable canners develop comprehensive computer-based information systems, we can expect a major expansion of management science methods in this area where there is a very clear correlation between profitability and capability to arrive at timely conclusions. Meanwhile, the lack of relevant analytic data - and an overwhelming complexity of problems is going to limit the application of mathematical methods.

H. Livestock Management

So much has been said in the literature about the application of linear programming to the formulation of optimal feed mixes that we do not have to dwell on the successes to any great extent. A good bibliography covering this subject can be found in Ref. 56. In a recent survey, several large food manufacturers with animal feed production operations have identified feed formulation as their most profitable use of computers. As a matter of fact, one of the recognized leaders in the use of management sciences in industry has seen fit to discuss their accomplishments in this area in their annual report to stockholders. Standard computer programs are now readily available (Ref. 47) to any new user who wishes to apply linear programming to feed blending.

Recent refinements in problem formulation, (Ref. 109 and 105) as well as a specialized treatment of particular application areas (Ref. 71, 86, and 89), indicate that the isolated problem of blending for optimum composition of nutrients at the lowest cost will gradually yield to more complex models encompassing a variety of environmental and dynamic relationships.

The transition from feeding of livestock to its use as meat is outlined in Ref. 3 and illustrated by models including purchasing, production, intermediate products, facility utilization and sales strategies (Ref. 103 and 104). Even though Snyder's model (Ref. 104) is focusing on the hog fabrication problem, there is no reason why a similar approach should not have a much wider applicability to a variety of produced foods such as dairy, fruit, vegetable, and cereal products.

I. <u>Procurement</u>

The evaluation of alternate supply strategies in the highly competitive environment within the food industry is going to keep the availability of any useful published information to a minimum·linear programming models are known to have been applied to the evaluation of procurement strategies for corn, wheat, vegetables (Ref. 96), coffee beans, cocoa beans, lard, and edible oils. One of the problems encountered in formulation of such models are flavor and other quality restraints which are more significant in the selection of ingredients for human consumption than in any other environment. Any firm wishing to extend the use of management sciences in the procurement of food ingredients will unavoidably encounter the need to develop quantitative measures for expressing its flavoring objectives.

The use of the transportation method is also indirectly related to procurement because inbound transportation and capacity restraints can materially affect the overall purchasing efficiency. References 67 and 57 illustrate the use of these techniques.

J. <u>Process Control</u>

The construction of mathematical models for the design of processing controls is a large and unexplored opportunity for management sciences. Quite a few references (Ref. 2, 28, 29, 32, 37 and 97) carry the implication that operations research models are used in mixing, batching, or blending of food products. As a matter of fact, closer examination reveals that only simple computations involving linear equations are applied in a fairly conventional sense.

It is the association of a blending process with a digital computer or analog computer (Ref. 44) which usually leads to the unwarranted notion that management science methodology is running the process.

As of this moment, a great many uses have been made of simulation techniques in engineering the performance criteria for process equipment. For instance, a California bakery chain has used a large simulation model to explore a number of alternative layouts for a complex production line requiring several queuing stations and calling for loading of finished products into a proper warehouse section. Another packaged foods manufacturer used a simulation model to examine reliability and queuing parameters for a complex conveyor belt system inter-connecting a number of packaging machines. A vegetable oil processor used computer simulation techniques to determine characteristics of a refining process prior to installing a computer for in-plant process control.

K. Production Scheduling

Even though the general literature on production scheduling demonstrates a variety of approaches to this problem, every reference that is quotable as a specific food industry application is relying on linear programming methods.

Two examples in the sugar industry (Ref. 46 and 76) show the interrelationship between harvesting and processing. Similarly, a dairy industry model (Ref. 100) ties in processing with market condition and Reference 51 deals with a more limited case of scheduling the blending process.

General statements about production scheduling methods and ways in which a linear programming solution should be formulated can be found as Ref. 45 and 55.

A typical application of these methods would be the story of a coffee processor who examined the cost of variable shift production vs. continuous standard shift production subject to capacity restraints in man power, warehousing and machine output. It turned out that extra shift production was the most profitable strategy.

In another case, a fruit and vegetable canner used linear programming to consider the quality of the available pack, equipment capacity, processing sequence alternatives, and variation in final demand.

The application of linear programming in these types of problems develops as a by-product valuable parametric data about facility planning, capacity restrictions, and other opportunities for capital investments (Refs. 68 and 88). Facility planning studies also rely on simulation methods (Ref. 60).

L. LOGISTICS AND DISTRIBUTION

The perishable nature of most food products, the low unit cost and large quantities handled have focused the efforts of management science teams within the food industry on opportunities to be gained from better distribution methods (Ref. 108). The improved logistics is achieved either by means of better allocation of finished goods to ultimate consumption points (Ref. 12, 16, 23 and 66) or by devising information systems which would facilitate seasonal (Ref. 61) or short-term planning (Ref. 107). Movements of finished goods, such as edible oil from Texas, the pineapple crop from Hawaii, and frozen vegetables from the Pacific Northwest to markets in the East, have been reported as subject to the "transportation method" technique. Various formulations of this method, along with powerful new computer codes which have recently become available, permit planning for seasonal demand, seasonal production, in-transit storage, origin and destination warehousing, as well as for full cost accounting that takes into consideration our complex freight structure, application of in-transit privileges, and warehouse handling costs.

A case which deserves attention is the application of mixed-integer programming to truck routing and truck dispatching (Ref. 99). This development has come to the USA from England where an especially imaginative approach to devising a useable and economic computer model has enabled a number of grocery and beverage distributors to achieve a measurable improvement in transportation efficiency. The lesson to be learned from this case is the importance of an international point of view when searching for successful O/R methods.

The problem of packaging dimensions and pallet arrangement design is related to distribution efficiency. For instance, management science methods are bound to influence the dimensions of cartons and boxes which are subject to a number of shelving, case-size, pallet-size, and warehousing restraints (Ref. 25). There are many other areas of distribution logistics, such as warehousing layout, optimum order picking sequencing, truck loading or unloading methods, etc. where the methodology of management sciences has a much greater generality than can be covered adequately in a paper restricted to the food industry.

M. INVENTORY MANAGEMENT

The development of the IMPACT (Inventory Management Program and Control Techniques) set of computer programs, which was introduced to the food industry in 1963, is a phenomena of particular significance. Before the IMPACT announcement only a small number of large corporations with adequate resources to support an O/R staff succeeded in installing comprehensive inventory management systems (Ref. 109). With the introduction of IMPACT, a massive educational effort, extensive reference literature, and a broad set of computer routines have become generally available to the industry producing a rapid acceleration in the adoption of inventory management methods. As of this moment, over 100 such systems are in the process of installation or in full operation among distributors of food products.

It is now clear that an extensive application of management science on an industry-wide basis must rely largely on the availability of "program packages" either from computer manufacturers, service bureaus, consultants, or universities. Considering the small average size of enterprises in the food business, the broad generality of key techniques and the scarcity of funds to do applications research and development, it seems that the availability of programming and educational resources would increasingly place the key responsibility for wide-spread industrial applications in management sciences in the hands of equipment manufacturers.[3] Whether the "hardware" oriented manufacturers will meet this challenge in the long run remains to be seen.

The available documentation on IMPACT is quite extensive. From general principles (Ref. 53) through comprehensive discussion of the underlying theory (Ref. 52 and 90) and case studies (Ref. 26, 49, 50, 85 and 94) a potential user has ample opportunity to learn the system.

The significance of IMPACT-type programs is well illustrated by a study (Ref. 83) showing how warehouse and in-store inventories affect food distributor profits. Current trends for direct computer tie-in between the manufacturers and distributors will result in standard inventory management models which would overcome many important limitations of existing applications and should take into account problems of joint economies between manufacturing and distribution.

3/ The rapid growth in the use of linear programming methods within the food industry can be likewise traced to the broad availability of well maintained and well documented computer programs through service bureaus and computer manufacturers.

N. INFORMATION SYSTEMS

The growth of management sciences in the food industry has now been inextricably tied in to the extension of computer-based management information systems to non-accounting uses of computers. There are still a few management science practitioners who may seek an organizational and functional role in the corporate structure apart from the computer environment. It is just a matter of time until it becomes clear that the management science professional is particularly well qualified to direct a corporate information systems activity. The rapid introduction of advanced techniques to industry is best illustrated by Slide 5 (Ref. 72). Another survey on the use of computers in the distribution of food products is summarized by Slide 6 (Ref. 92). The pervasiveness of information systems seems to extend all the way to agriculture (Ref. 48) and appears to be one of the pre-requisites for entry of management sciences into short-term decision-making anywhere in the food industry (Ref. 43 and 31).

The marketing orientation of the American food industry can be considered as the basic driving force behind the high productivities achieved in meeting consumer needs. The allocation of store shelf-space to individual products becomes a key requirement in proper industry planning (Ref. 15, 27 and 79) and suggests an important mission for management science analysis. Unfortunately, an adequate data base (which would permit the evaluation of alternate marketing strategies as competition becomes more intense and new product introduction cycles become shorter) in the present environment is exceedingly difficult to obtain and to use in a meaningful form. The implementation of marketing intelligence systems allowing scientific analysis of the marketing environment will have to wait until individual firms acquire a broadly based marketing information retrieval capability. Ref. 75 is the only known published work in this sensitive area where an early break-through may give any company a competitive advantage.

O. MARKETING RESEARCH

There are several thinkers in management sciences who believe that the current unique identity of an "O/R Analyst" or "Management Scientist" is purely a transitional phenomenon. They feel that management science methods will become pervasive throughout all industrial fields and there will be no need for a separate professional discipline because production, industrial engineering, financial, distribution, or marketing personnel will incorporate quantitative analysis into their own repertoire of techniques.

This transition may have already taken place in the area of market research, which has quickly adopted several statistical methods for mathematical model-building. References to sales forecasting models based on regression analysis are numerous. Sales of butter, canned fruit, bakery goods, pineapple, breakfast cereals, and breakfast beverages have been analyzed by standard analytical programs available from computer program libraries.

Marketing research has employed a variety of techniques to study brand loyalty (Ref. 110 and 112), demand (Ref. 80 and 84), and sales organization (Ref. 73). The methodology of decision theory seems to be particularly applicable to the complex interactions in the market (Ref. 11 and 13). The capability to extend these methods is running into the inherent limitations of the available data base; useful and low-cost means for the analysis of information are not, as yet, available. However, the beginning of an industry-wide information system is already in existence (Ref. 6 and 30).

The concepts of large scale simulations for marketing purposes can also be found in some of the "management games" which have recently been released (Ref. 4 and 5). For instance, the Dairy Management Game simulates the market environment in which several dairy processing and distributor enterprises compete for sales in a geographic area. The game calls for at least 14 resource allocation and pricing decisions per enterprise, per play. Since isolated data gathering and model building can keep absorbing unlimited amounts of computing and analytic resources, it is likely that any integrated marketing research models of the future will be constructed along lines suggested by the structure of some of the existing games.

P. NUTRITION AND CONSUMPTION

The subject of diet selection is one of the classical applications of management sciences and needs little further elaboration. Recent works about food blending (Ref. 19 and 36) and about special minimization problems (Ref. 8) rely on well defined linear programming methods. A sequential problem in menu planning has been discussed in Ref. 7.

R. MANAGEMENT SCIENCE METHODOLOGY IN THE FOOD INDUSTRY

It is unfortunate that despite extensive literature about various aspects of management sciences as applied to specific problem areas within the food industry, little has been written (Ref. 38 and 108) about the methodology of research and implementation of such projects. Even though management scientists advocate a systematic approach to all problems in their environment, relatively little is known about a systematic approach to productive uses of management science itself. The doubts in the minds of key industrial executives about the effective uses of computers (and of management sciences) (Ref. 93) should be an adequate incentive for good work which would catalogue and evaluate the broad industrial experience to date. This should be done by a more frequent convocation of industry symposia (Ref. 18, 38, 40, 45, 56, etc.) or by stimulating the preparation of state-of-the art articles (Ref. 87 and 102) such as this one.

S. CONCLUSION

The productivity of the food industry is a matter of great importance not only in advanced industrialized countries, but also everywhere in the world today. There is no doubt that management sciences will have a significant role to play in identifying the means for increasing the contributions of the food industry to human welfare.

A. INDUSTRY DEFINITION

1. GROWING FOOD PRODUCTS (Agriculture)

2. INTERMEDIATE PROCESSING (Livestock & Livestock Products)

3. FINAL PROCESSING (Manufacturing)

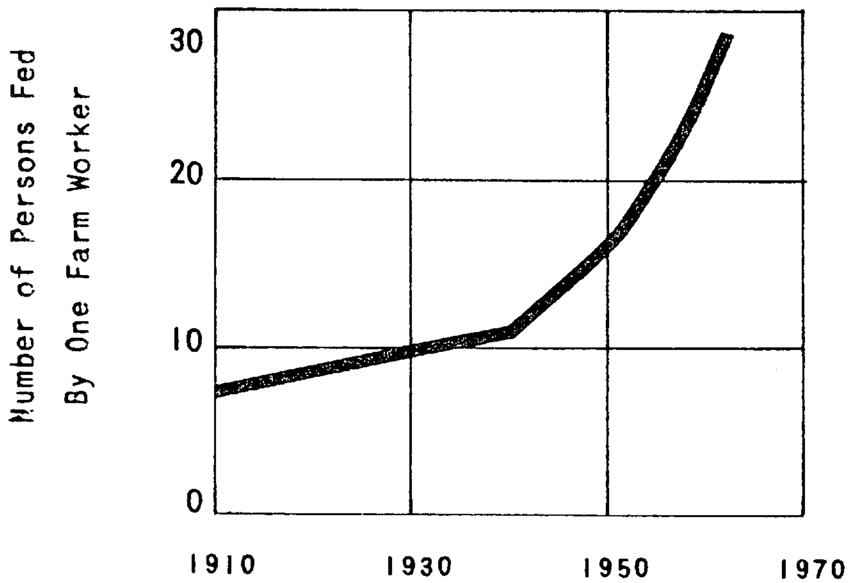
4. CONSUMPTION (Marketing and Distribution)

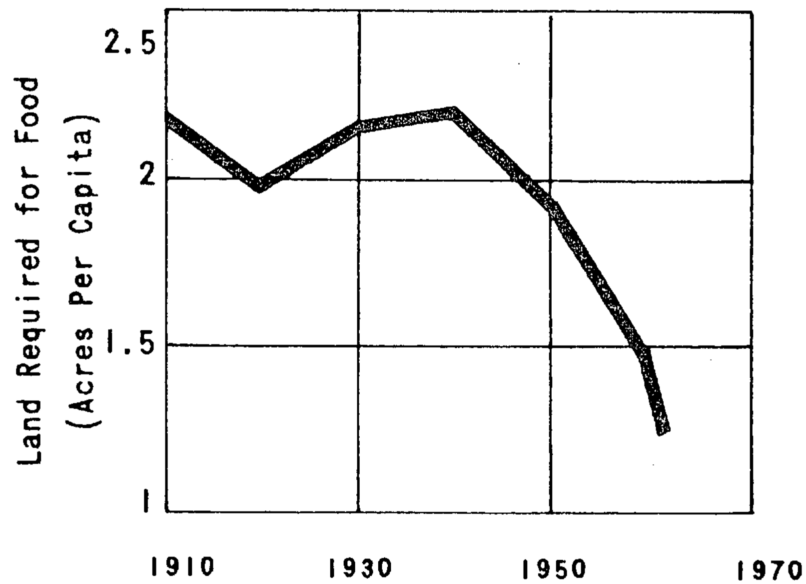
B. IMPORTANCE OF FOOD INDUSTRY

Industry Class	Output Designation	Contribution to GNP (in Billions $)	% of GNP
8	Food and Kindred Products	$ 84.7	14.2 %
54	Livestock and Livestock Products	$ 32.7	5.5 %
55	Miscellaneous Agricultural Products	$ 30.1	5.0 %
56	Agricultural and Fishery Services	$ 2.0	0.3 %
	Food Industry Sub-total	$ 149.5	25 %
	Other Industry Contributions	$ 450.5	75 %
	Total GNP	$ 600.0	100 %

Slide 3

PRODUCTIVITY OF U.S. AGRICULTURE





Source: SCIENTIFIC AMERICAN, VOL 209, No. 3, p. 80

Slide 4

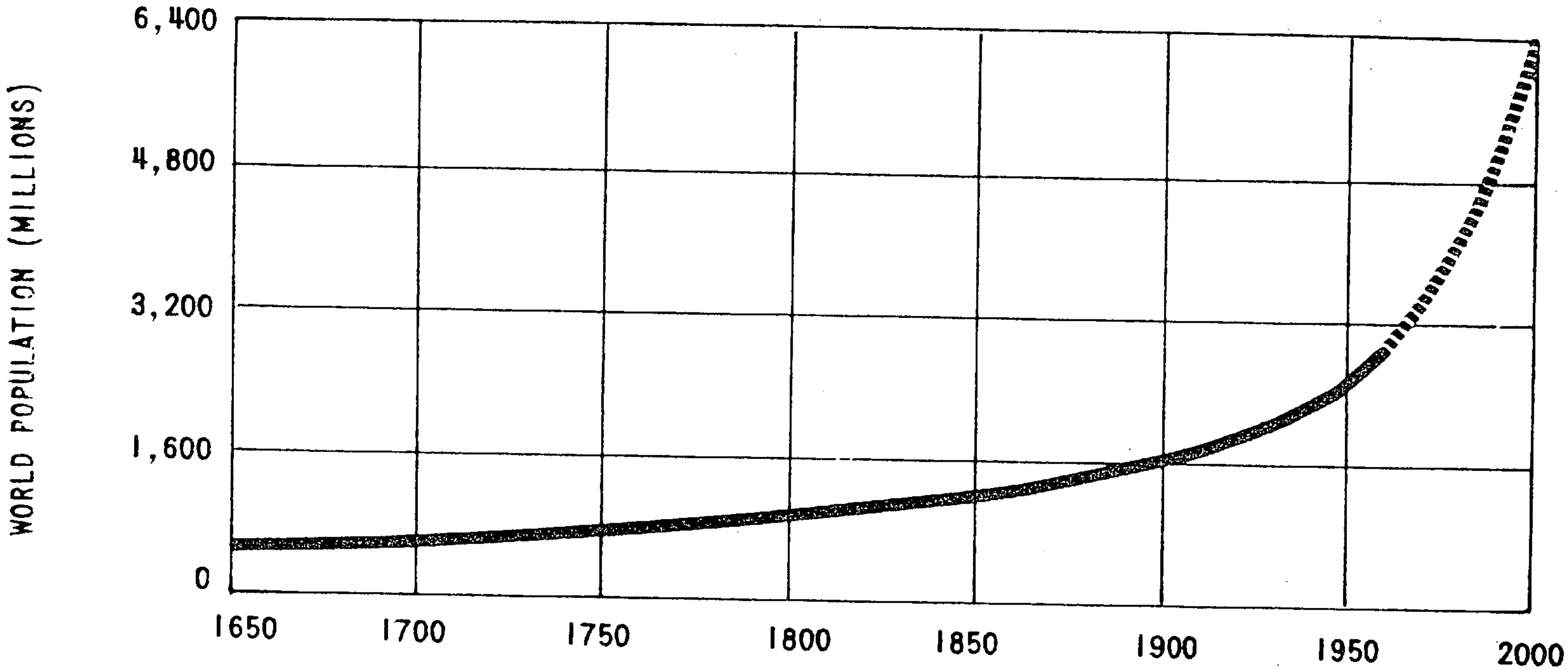
HOW WHOLESALE GROCERS USE E D P

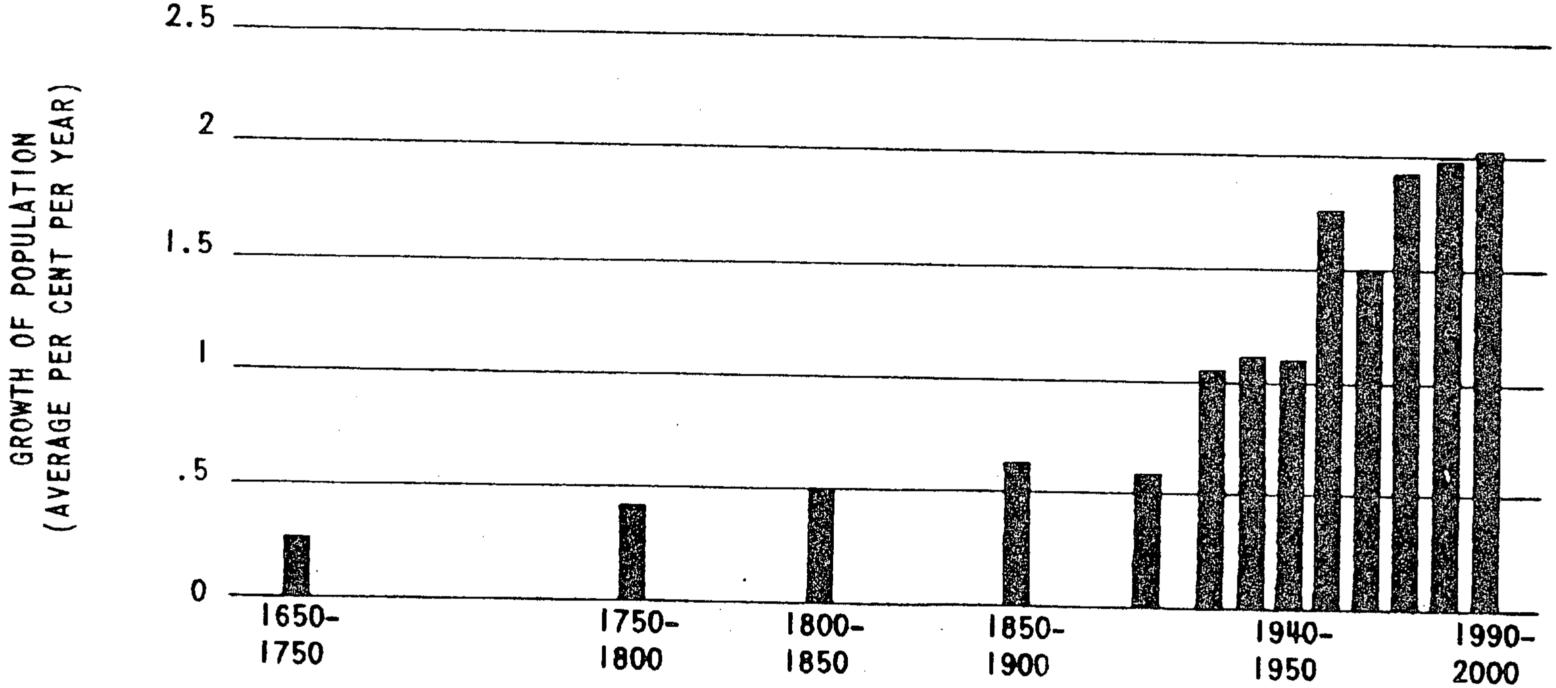
	% of use for each purpose
Space Allocation in Warehouses	46 %
Sales Forecasting	36 %
Automatic re-ordering	52 %

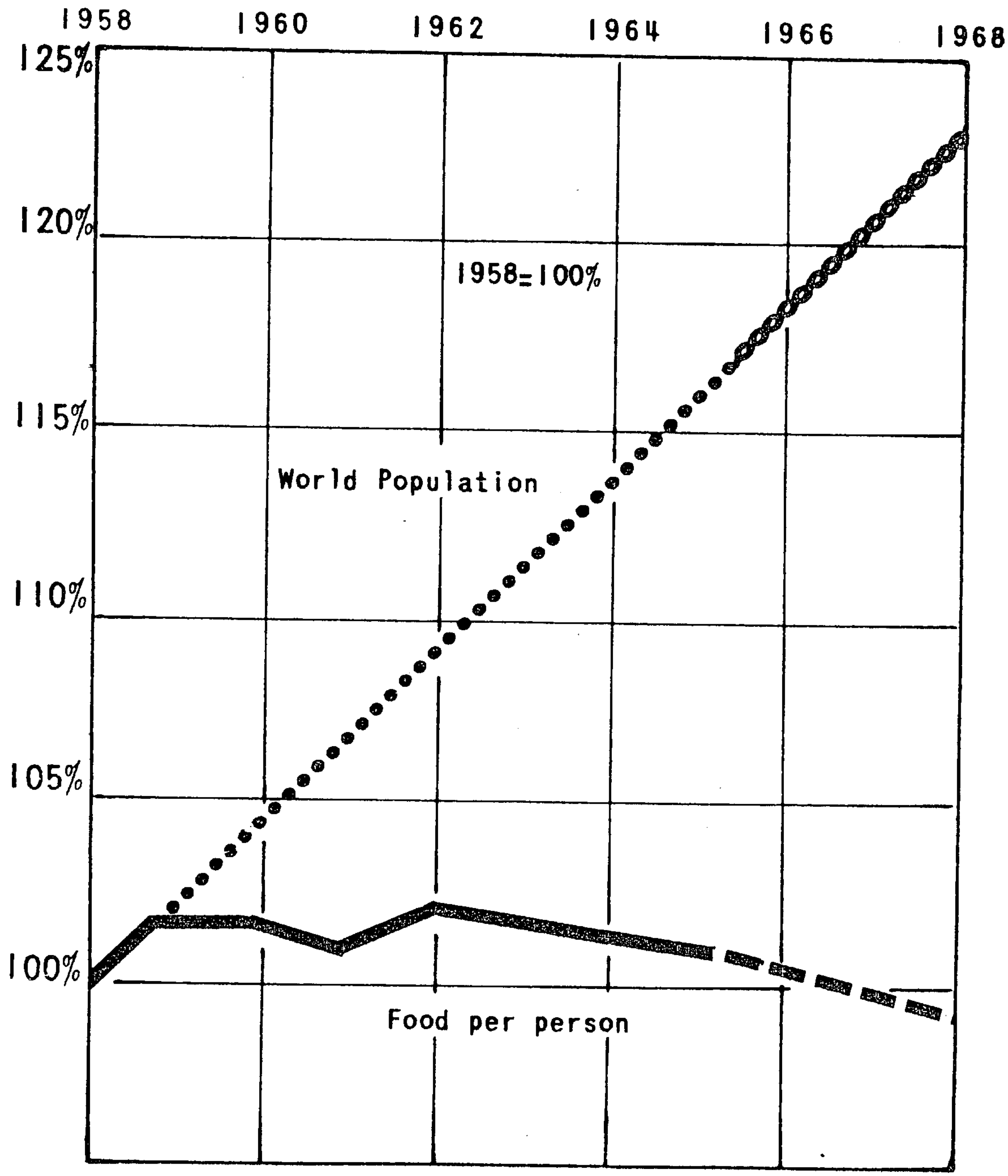
% OF FIRMS USING E D P EQUIPMENT

	% now using
Sales under $ 1 Million/Annum	3 %
Sales $ 1 - $ 5 Million	6 %
Sales $ 5 - $10 Million	37 %
Sales $10 - $25 Million	48 %
Sales over $25 Million/Annum	92 %

Source: Progressive Grocer, April 1965 Survey Results


WORLD POPULATION (MILLIONS)
6,400
4,800
3,200
1,600
0
1650
1700
1750
1800
1850
1900
1950
2000


GROWTH OF POPULATION
(AVERAGE PER CENT PER YEAR)
2.5
2
1.5
1
.5
0
1650-
1750
1750-
1800
1800-
1850
1850-
1900
1940-
1950
1990-
2000


1958
1960
1962
1964
1966
1968
125%
120%
115%
110%
105%
100%
1958=100%
World Population
Food per person

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