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The Application of Genetic Algorithm to Supply Planning Systems in the Food Industries

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Abstract:

In the food industries, great importance is placed on the appeal of freshness to consumers, and it is thus necessary to draw up a highly accurate supply and demand program for providing such appeal. The author has provided supply planning systems each configured with a genetic algorithm as its core. This paper outlines requisites for the systems, their functions and the methodology for developing the systems.

1. Introduction

In the food industries, great importance has been placed on the appeal of freshness to consumers. The appeal of freshness requires that producers supply the necessary amounts of their products to necessary places within a set time while keeping the specified level of freshness that consumers require. In order to meet such requirements, it is necessary to draw up an overall supply program. This program must be based not only on shortening of transportation time from production sites to final retail shops but on sufficient supply (both amount and quality) of products according to demands which generally fluctuate due to numerous factors.

When drawing up supply programs, major food corporations start with the allocation of supplies from dispersed production sites to demand regions all over Japan. Relationships between demand regions and supply sites are rarely static, but rather dynamic connections are made as occasion demands because of demand fluctuation, supply side ability, supply and demand balance, and so on. Concerning supply side ability, the number of production workers usually places a severe constraint on production ability. This constraint has, in extreme cases, caused some corporations to make a daily production plan for each line at a production site and to examine not only facility ability but also to assure that there is sufficient supply of human resources when allocating demands to respective production sites.

In the present circumstances, a supply program is drawn up typically by highly specialized staffs on a divisional basis, who belong to the general production division or the general logistics division of a head office. Increased importance on freshness management has resulted in a shorter cycle of revising a supply program. An effort to follow the tendency of diversified consumer needs has resulted in an increase in the number of easily treated items, which makes it impossible for supply programs to be made solely on the divisional basis by specialists. Consequently, stockouts or overstocks have become serious problems in some cases.

Under these circumstances, great expectations are now placed on the developments of systems which can give considerable assistance to supply planning. The author has constructed several supply planning systems to be used in the food industries. This paper presents a general outline of requisites for supply planning systems, their functions and the methodology for developing the systems for the food industries.

2. Features of Supply and Demand Program and Outline of Supply Planning in the Food Industries

2.1 Features of food supply and demand

Food demands are greatly influenced by a variety of factors including weather conditions, large-scale local festivals and other events, decisions in the downstream side of a supply chain, changes in consumer tastes, and so on. Demands cause complex and great changes from year to year on the basis of trends or daily events or both. Increased importance placed on freshness now requires delivery to retailers to be within 1/5 to 1/10 the number of days set for a product's freshness period. Such a situation determines an upper limit for stocks held by producers and, if overstocks occur, the products may be wasted in the worst cases. Delivery lead time from receiving orders to shipping has been shortened year after year, and even foodstuffs that are not delivered on a daily basis tend to be shipped next day after receiving orders. Under such a severe demand environment, it is necessary to put into proper practice a production supplement program for maintaining optimal stock levels.

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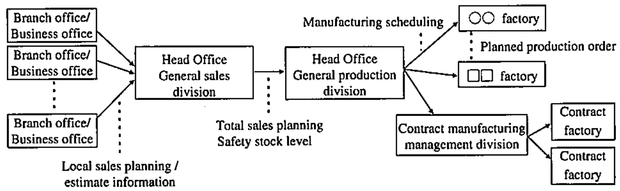


Fig. 1 Flow of supply planning business

2.2 Outline of supply planning

A general sales division integrates and adjusts sales estimates and plans sent from branch and business offices spread all over the country, and decides stock levels on the basis of an overall sales plan and for sales purposes. Information regarding stock levels is sent to the company's general production division, which then allocates supplies to production sites in the country. For most products excluding such daily delivered foodstuffs as milk or bread, static connection is rarely made between demand regions and supply sites.

For example, corporations in the beer industry have their breweries dispersed around the country, and their business plans are based on demand-region oriented production. But production volume allocation is carried out as occasion demands according to supply side logic which gives consideration to such factors as a weather conditions, demand fluctuations or concentrated production of secondary products. Each factory makes a detailed program (manufacturing scheduling for each line) to meet the allocated volume by utilizing available facilities and human resources (see **Fig. 1**). This is how supply planning is generally carried out concerning foodstuffs which are not delivered on a daily basis. Actual division of labor among the general sales division, the general production division and the factories varies from corporation to corporation. At this stage, programs are often drawn up with a last packing or packaging process in mind. It is attributed to the fact that facility or business systems are constructed on the basis of a determinate program including a series of steps from preparing, supplying of raw materials and other materials, to final product packing.

3. Outline of Supply Planning Systems for Food Industries

3.1 Function and configuration of supply planning systems

This section describes the module configuration of supply planning systems and the functions of each module.

Fig. 2 illustrates a system module configuration. The module configuration shown comprises (1) Demand planning module, (2) Distribution planning module, (3) Production planning module and (4) Supply chain inventory module for organizing the functions of (1) to (3). The functions of the respective modules are summarized as follows.

(1) Demand planning module: a module for inputting a corporate integrated sales plan for each item and setting its stock level. A pre-stage function of integrating and analyzing sales plans and estimates sent from branch and business offices dispersed in the country and thereby setting overall corporate demands is currently provided by other systems or concerned divisions. This function is called sales forecasting or demand forecasting, and many of supply chain planning related packages are now attracting much attention in the US and other countries and include demand planning modules incorporating various forecasting methods. Nippon Steel Corp. intends to make future plans with such functions in mind.

(2) Distribution planning module: a module for allocating supplies

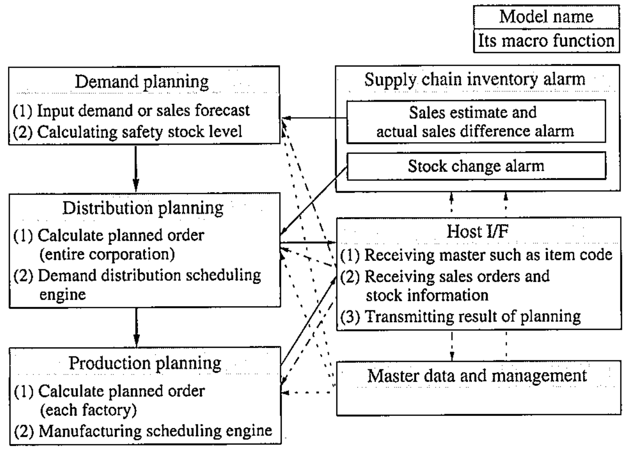


Fig. 2 Module configuration of supply planning system

to production sites on the basis of a sales plan for each item, with its stock level set by the demand planning module. A matrix is made between a demand axis for each item and a supply axis for each production line on a monthly or weekly basis. Then, supply distribution is planned according to the demand axis and availability of factory facilities and human resources on the supply side. If planning of supply distribution is impossible on the basis of a unit period, then production or stock adjustment will be tried on the basis of a longer period. Raw materials and other materials must be supplied to follow a packing or packaging process plan. In the case of a product like beer which needs a ripening period and has no substitute supply means, factory resources of only main raw materials may be added to constraints in the supply side.

(3) Production planning module: a module for allocating periodic demands and human resources to respective lines according to a distribution plan. On the basis of line demands (an item stock level, initial inventory and a working system), a daily plan is made to meet the conditions of various production line facility limitations (item production volume per hour, preparation change time, secondary product items sequence constraint, and so on).

(4) Supply chain alarm system: for supply planning, the largest external disturbing factor is demand fluctuation. The number of items generally sold by major food corporations all over the country often exceeds 1000. In order to put supply programs into proper practice without any interruption, it is essential to monitor deviations from calculated demands and resulting changes in stocks on a daily basis and detect any abnormalities as early as possible to reflect them in a supply program. Actual demands are affected by a combination of natural and artificial factors including weather conditions that are difficult to predict and preferences on the retail side. Thus, forecasting of actual demand is not a problem that can be solved completely even by introducing a demand forecasting system. The present supply chain alarm system obtains differences between estimated sales and achievements on a daily basis, selects items to be checked and sends the list of these items with related information to the staff in charge of sales planning. The staff in turn makes judgments based on the received information. The present system can, when a sales estimate is changed, also check changes in stocks by giving consideration to a current stock level and an on-going production plan, and present a list of items likely to run short together with related information to the staff in charge of production planning.

Fig. 3 illustrates an operation image of using the foregoing modules. Food supply planning generally operates by executing plans periodically, for example on a monthly or weekly basis. However, the supply chain alarm system enables non-periodic plan revisions to be made by supplying information on situation changes including differences between estimated sales and achievements, differences between an estimated stock level and an actually needed level, and so on.

Next, distribution planning and production planning as core functions in the present system will be described in detail.

3.2 Distribution planning module

3.2.1 Calculating required amounts

A required supply amount is calculated from information regarding a sales estimate, stock upper and lower limits and current stock level, and then supply distribution is decided. Reference stock levels based on multiple ideas are prepared. For example, those ideas may be (1) maintaining of an intermediate level between stock upper and lower limits and (2) securing of a stock up to its upper limit when the lower limit is reached (see **Fig. 4**). A user can select any reference stock level when planning.

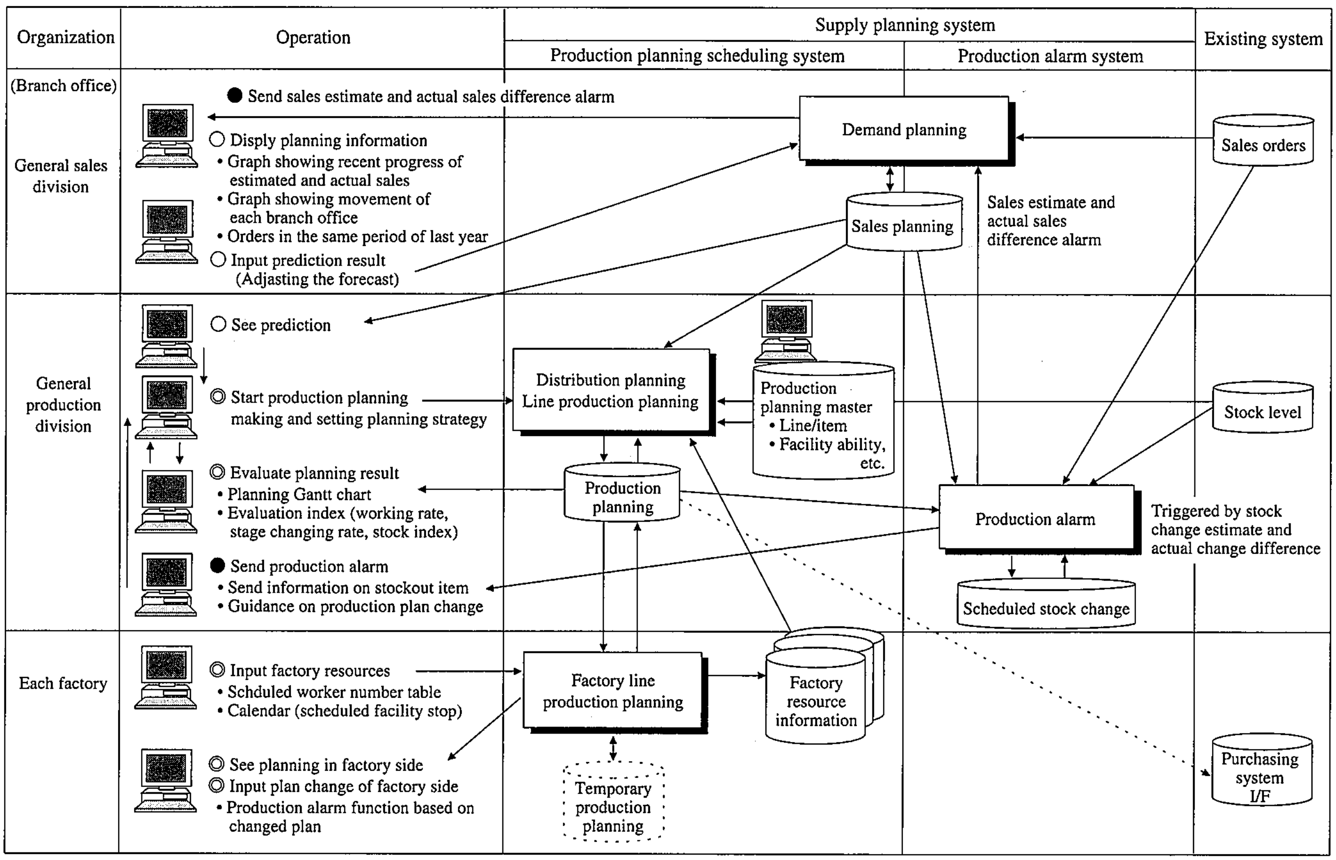
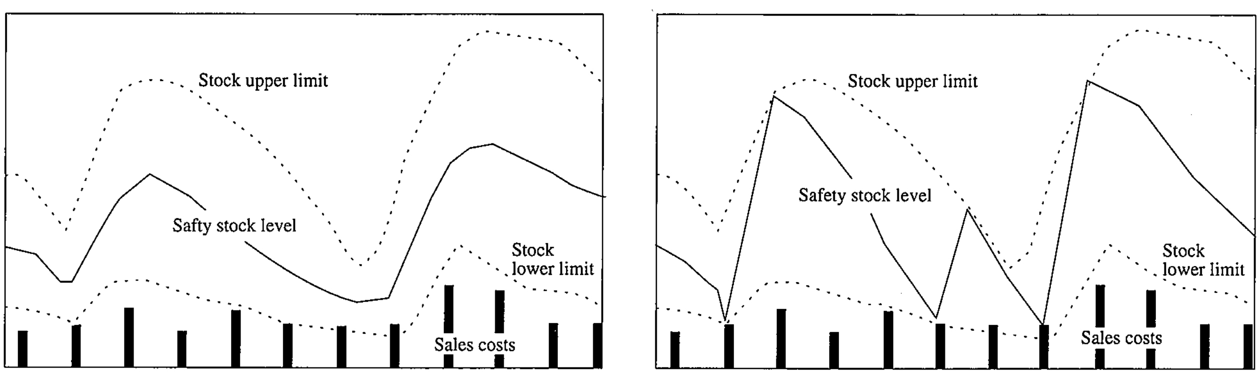


Fig. 3 Operation flow of supply planning system



Example 1 of required amount calculation pattern :
Daily production amount calculated by including shipping costs for maintaining an intermediate level between stock upper and lower limits is set as a required amount.

Example 2 of required amount calculation pattern :
Daily production amount calculated by including shipping costs for recovering stocks up to the upper limit when the lower limit is reached is set as a required amount.

Fig. 4 Example of required amount calculation pattern

3.2.2 Conditions to be considered for distribution planning

Under the preconditions of a required supply amount set on the basis of a unit period (month or week) and facilities and human resources in the supply side, distribution of required amounts is decided for respective lines (groups) of a production site. Representative conditions to be considered here are as follows: (1) items to be produced at each line, (2) line facility ability, (3) line working ratio (non-operation time such as stage changing time is represented), (4) working system (time) for each factory or line, (5) number of workers at each factory, and (6) required number of workers for each line working system. For these conditions, values master-defined beforehand are used. Strategic conditions that are similarly master-defined include (1) strategy for each factory (mass production factory or factory designed for dealing with demand fluctuation), (2) strategy for each category (mainly decided by a delivery date after manufacturing) and (3) strategy set for each planning (importance of productivity or standardized working system).

3.2.3 Distribution planning engine

Supply amounts decided under the foregoing conditions are allocated to the cells of a matrix between a demand axis for each item and a supply axis for each line, and a solution is found in which the total of the demand axis side can meet demands and the result of collecting human resources necessary for each factory can provide the necessary number of factory workers (see **Fig. 5**). In order to find a solution that satisfies the foregoing conditions, one selected from a classic OR method such as LP, and an AI or simulated annealing method may be used. Evaluation of effectiveness varies from user to user.

The authors compared and examined cases in which application of various methods in the steel business including their successes and failures. As a result, the authors decided to use GA (Genetic Algorithm) as a planning engine. Currently used is a GA library developed by Research and Development Center of Electronics & Information Systems Division, Nippon Steel Corp. GA is a method developed on the basis of the theory of evolution which argues that living things evolve by crossing genes. Solutions are expressed by "genes" and, by repeating solution crossing, the solutions selected by the survival of the fittest can be evolved (see **Fig. 6**). GA is characterized by system performance that needs no solution logic and enables solutions to be evolved for the better as long as a solution evaluation measure can be defined.

The difficulty of applying GA to distribution planning is that the number of combinations is extremely large in the case of a matrix of, for example 1000 items × 50 lines, and thus real time processing is impossible. To deal with this difficulty, the concept of sub-category is introduced and then items identical in terms of the foregoing conditions are lumped together. Accordingly, item

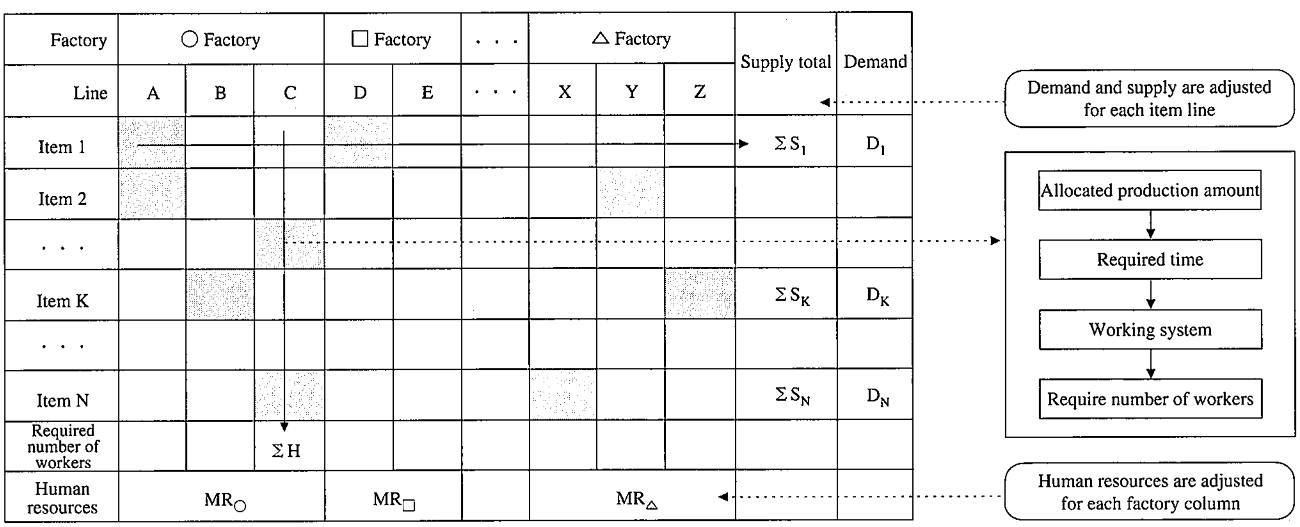


Fig. 5 Concept of supply distribution problem

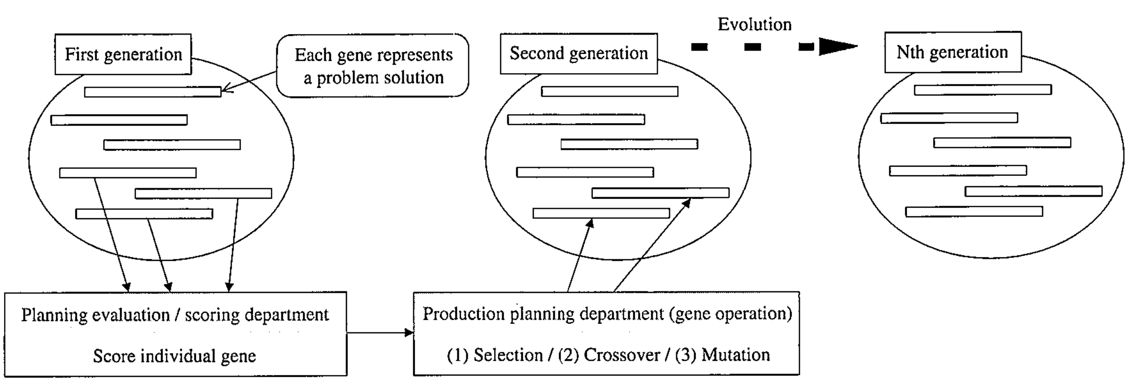


Fig. 6 Principle of GA (Genetic Algorithm)

axes can be reduced usually by order units. For example, the size can be reduced to a matrix of 50 × 50. At this stage, however, considering execution time, the task of finding a solution cannot be solely left to GA. Experience shows that even for the matrix of 50 × 50, the number of cells to be used is lower than several tens of percentage points, and the number of sub-categories manufactured by multiple lines is lower than half. Accordingly, the difficulty of applying GA is solved by reducing a genetic structure to as small as possible and then leaving the task of processing to GA.

3.3 Production planning module

Daily production planning is carried out on the basis of a required amount for each line set as a result of distribution planning and a working system for each line.

1) Conditions to be considered for production planning: in addition to the conditions for required amount distribution planning and the strategic conditions, facility and previous process conditions must be considered. For example, the following conditions must be considered: (1) item feed sequence and same day prohibition condition, (2) necessity or impossibility of simultaneous manufacturing decided by facility use among lines, and (3) productivity increase preparation time minimizing sequence.

2) Production planning engine: in order to find a solution in real time, the following two-stage processing is carried out. (1) Multiple strategy oriented solution to be executed is found by search type algorithm, and (2) this solution is transferred to GA as an initial solution and thereby a strategic oriented solution selected by GA is evolved[*1].

4. Methodology for Developing Supply Planning Systems

Recently, an enterprise resource planning package represented by SAP or ORACLE[*2] applications has been a focus of attention. This package was developed to apply a business model packaging a collection of various business forms to a user's specific business form by selecting a particular module or parameter. The existing scratch type system attracts attention as it provides means for dealing with rapid changes in a business environment.

On the other hand, in the field of supply planning, no packaged products are commercially available. Application of an enterprise resource package is not considered for this field. It may be due to the fact that in supply chain planning much depends on the thinking and judgments of the specialized staff and cannot be realized simply by transfer logic, close and complex combination of individual factors including a corporate sales system, a supply system, product strategy, and so on, as well as the difficulty of integration as a package.

However, construction of a supply planning system by means of the existing scratch type method also faces a difficulty. It is known that much labor is necessary for extracting and systematizing planning logic and verifying the result of the established logic. In addition, past experience shows that if some defective portions exist in the developing process, the established system must be abolished and construction must be started all over again.

A main problem is that supply planning depends heavily on the thinking process of a planner and processing is carried out based on his intuitive ideas which cannot be expressed in words. Further, since the planner continues planning without expressing his thinking process as a logical sequence, it is extremely difficult to explain the details to SE (only surface ideas may be explained).

The authors use a template engine developing method[*3] for the purpose of making efficient a knowledge obtaining and verifying process. Basic ideas are as follows: (1) discussion based on answers (result of planning) provided by the system for actual demand and supply side resources makes knowledge obtaining and verifying more efficient, (2) even if individual factors differ among corporations, compatibility is maintained between the line and column of a matrix, i.e., between the item line of the demand axis and the manufacturing line or human resources column of the supply axis and, accordingly, a "skeleton portion" of the engine can be used again as a template, and (3) also for production planning, a basic idea is that demands and a safety stock level are met under the condition of a working system and, accordingly, under the foregoing constraints, main raw material sources and a skeleton portion including a line container replacing condition, and so on, can be shared in the food industry.

Even if planning logic differs among corporations, in many cases, peripheral portions can be used as templates, for example displaying data models or the results of planning from various standpoints.

5. Conclusions

Requisites for supply planning systems, their functions and the methodology for developing the systems have been described above in a general manner.

In the planning systems, a first key to success is to accurately extract and systematize requirements such as constraints or objective functions at an initial stage and, secondarily, it is important to find solutions (key technology). In an effort to provide novel systems and developing methods different from others, the authors developed a GA method as a planning engine based on past experience in the steel business and thereby established a bridgehead in the food industries. In the future, Nippon Steel Corp. intends to expand further in the food industries and also in other manufacturing industries for the planning business.

[*1] Put GA into practice on the basis of a degree of coincidence with given evaluation reference strategy, and obtain a solution suitable for the strategy.

[*2] ORACLE is the registered trademark of ORACLE Corporation.

[*3] Methodology for first using a "template" having only a solution skeleton and then adding other necessary portions (logic, conditions, and so on) according to purposes.