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다양한 납기일 형태에 따른 다제품 생산용 회분식 공정의 최적 생산계획

Optimal Scheduling of multiproduct batch processes with various due date

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Abstracts In this paper, scheduling problem is dealt for the minimization of due date penalty for the customer order. Multiproduct batch processes have been dealt with for their suitability for high value added low volume products. Their scheduling problems take minimization of process operation for objective function, which is not enough to meet the customer satisfaction and the process efficiency simultaneously because of increasing requirement of fast adaptation for rapid changing market condition. So new target function has been suggested by other researches to meet two goals. Penalty function minimization is one of them. To present more precisely production scheduling, we develop new scheduling model with penalty function of earliness and tardiness We can find many real cases that penalty parameters are divergent by the difference between the completion time of operation and due date. That is to say, the penalty parameter values for the product change by the customer demand condition. If the order charges different value for due date, we can solve it with the due date period. The period means the time scope where penalty parameter value is 0. If we make use of the due date period, the optimal sequence of our model is not always same with that of fixed due date point. And if every product have due date period, due date of them are overlapped which needs optimization for the maximum profit and minimum penalty. Due date period extension can be enlarged to makespan minimization if every product has the same abundant due date period and same penalty parameter. We solve this new scheduling model by simulated annealing method. We also develop the program, which can calculate the optimal sequence and display the Gantt chart showing the unit progress and time allocation only with processing data.

Keywords due-date period, earliness, tardiness, penalty, simulated annealing

1. INTRODUCTION

The competition grows in market and also researches have been followed. In order to survive, highly cost efficient production is required. So the scheduling has been getting attentions. This research deals with the scheduling of multiproduct batch processes. Batch process is the production form having the advantage over high value added low volume products. We can manufacture with relatively lower investment compared to continuous process with batch process agreeing with market condition. A review of advances can be found in Reklaitis(1991).

The batch process has two general form, multiproduct process and multipurpose process.

Multipurpose is used for products with dissimilar recipes and longer campaign lengths. So scheduling of multipurpose process has three solution components: production plan, production line configurations and detailed production line schedules.

In multiproduct process, all products require the same processing tasks in the same order at serial stage similar to flowshop type. Product is manufactured one at a time. And derivative process is the network flowshop and parallel flowshop process. Its research concentrated on making the relation and model that can select the optimal production sequence rather than assignment of jobs to equipment units.

Scheduling is composed of macro level problem, production planning and micro level problem, short-term scheduling. Macro level concerns the determination of production goals over a specified time horizon given marketing forecast for prices and product demand. And micro level involves choosing the sequences in which various products should be processed at equipment so as to meet the production goals that are set by the planning problem. So efficient utilization among the multiple products to satisfy the goals matters.

This research deals with scheduling of micro level problem. The goal is the maximization of customer satisfaction and minimization of production at the same time. This can be initialed by the introduction of JIT(just in time) concept. Preventing unnecessary inventories, they can reduce the production cost and raise customer satisfaction. In chemical process scheduling studies also imported the idea, Ku *et al*(1990) suggested the object of scheduling as meeting the due date for multi unit serial multiproduct process. They suggested single product campaign scheduling with branch and bound method and heuristics. The product produced late for the due date is charged with tardiness penalty. So the task is minimization of penalty. But their research is limited because they did not take inventory cost into account. To mere plan schedule for minimization of tardiness may cause long waiting inventory to process. It increases the production cost and needs unnecessary investment. We have to consider inventory and customer satisfaction at the same time. And their heuristic is so narrow scoped that it can not apply for only 5% of whole scheduling problem.

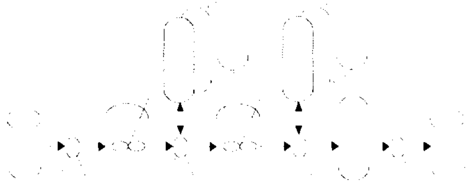

그림 1. 일반적인 회분식 화학공정

Fig.1 General diagram of chemical batch Process

While Ku *et al*(1991) used branch and bound method and mathematical programming method, we are going to use simulated annealing method. It is one of the evolutionary algorithmic methods. It is apt for solving the problem with many independent variables like the products in our scheduling matters. We are going to describe this by formulating the problem, and presenting the evolutionary solution method- simulated annealing, and example analysis.

2. Problem definition

Let N denote the number of products to produce, M, the number of stage for products to go through. And we take one customer order one product on a certain due date and we can take product can be made only one batch. Product has index i, with stage j. So C_{ij} is the completion time of j stage in i th product. Our research aims to calculate the due date of i product, so the due date of i product is d_i. The penalty has two kinds, earliness penalty and tardiness. So the earliness penalty parameter of i product is α_i and tardiness penalty parameter is β_i. The penalty of i product is P_i . minimum completion time as an objective function. Makespan is the completion time of the last product produced at the final stage.

IST(Intermediate storage tank) policy determines the main scheduling problem. UIS,NIS,FIS,ZW are the examples. We can refer Kim,M *et al*(1996). The difference of these polices is the number of IST between stages. UIS(Unlimited intermediate storage) policy is to take enough numbers of ISTs that gives process with ample inventories.

considered here is UIS (Unlimited intermediate storage) and NIS policy. UIS takes infinite ISTs between stages. So the completion time of i product at j stage can be decided as

$$C_{ij} = \mathrm{Max}[C_{ij-1}, C_{i-1j}] + t_{ij} \qquad (1)$$

We can better understand with Fig.2.

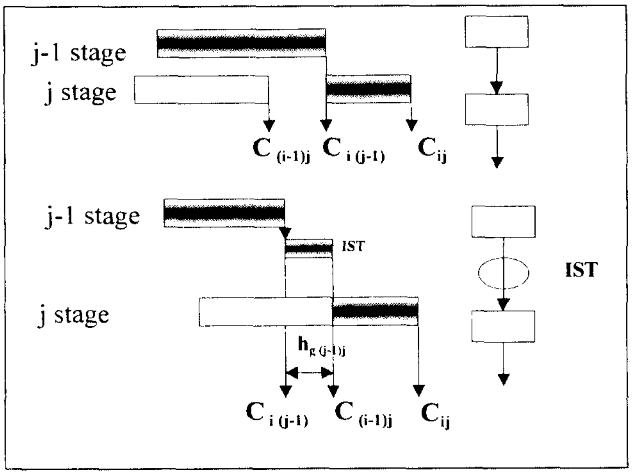

그림 2. UIS 방식에서의 조업 완료시간 결정
Fig.2 Completion time decision in UIS policy

And NIS is not to take IST between the stages, material is kept in the equipment itself without IST. So the processing time of NIS is the sum of genuine manufacturing time and holding time. So the completion time can be decided as

$$C_{ij}=\mathrm{Max}[C_{(i-1)j}, C_{(i-1)(j+1)}-t_{ki\,j}]+t_{ki\,j} \quad j=1 \qquad (2)$$

$$C_{ij}=\mathrm{Max}[C_{i(j-1)}, C_{(i-1)(j+1)}-t_{ki\,j}]+t_{ki\,j} \quad j=2\text{-}M \qquad (3)$$

The completion time of the last stage,M produces i product is C_{ij}. So we take this as the completion time of i product at the process. So the difference between C_{ij} and customer due date make the penalty. That is , completion time is bigger than d_i, then the product charge tardiness penalty for violating the expectation of customer. So we calculate tardiness penalty(T_i) by multiplying tardiness penalty parameter α_i with difference. And completion time is smaller than due date, it charges earliness penalty. So we calculate the earliness penalty(E_i) by multiplying difference with difference from difference with due date and completion time. And we take S as the single product campaign sequence. Then we can decide the penalty as follows

$$E_i = max\,[\,0, d_i\text{-}C_{iM}] \qquad (4)$$

$$T_i = max\,[\,0, C_{iM} - d_i\,] \qquad (5)$$

$$Penalty = f(S) = \sum_{i=1}^{N}(\alpha_i E_i + \beta_i T_i) \qquad (6)$$

The objective function becomes the minimization of $f(S)$.
We take this by the assumption that from previous experience gave the data for the parameter of earliness and tardiness. They are thought to be given in advance.

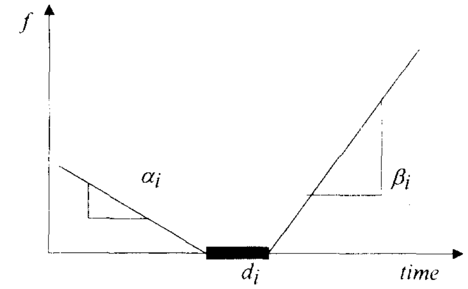

그림 3. earliness 와 tardiness 를 고려한 목적함수의 형태
Fig. 3 objection function with earliness and tardiness

While we generate the schedule considering customer due date, In real plant, customers want to get their orders for a given days. not a single days. The order of customers may be the intermediate products decided by other plant condition. So they want to be delivered the material(products) by their own condition. Suppliers produce the products by that period. To reflect this, we should change our object to place earliness penalty if the product is ready before the initial due date(Ped_i), then place tardiness penalty, and if the product is not ready even after the final due date(PEd_i), we charge tardiness penalty by the difference of Ped_i and completion time . so the (4), (5) have to change as

$$E_i = max\,[\,0, C_{iM}\text{-}PEd_i] \qquad (7)$$

$$T_i = max\,[\,0, PTd_i\text{-}\, C_{iM}\,] \qquad (8)$$

To display penalty with adapting due date period , we can get Fig. 3.

The start of due date period can be analyzed also by the parameter change. The earliness and tardiness penalty is given by the difference from completion time and due date. The parameter value may be dependent on the that difference. If the difference is bigger than certain degree, a more serious penalty may be given on that schedule. On the other hand, if the difference is small and within some degree, we can take that schedule with less penalty. And this allowances gives the concept of due date penalty period from the viewpoint of manufactures.

From the new algorithms, we will solve our new scheduling problem using simulated annealing. And examples will be followed.

3. Simulated Annealing

3.1 Heuristics and evolutionary method

Scheduling problems are considered of many products, stages, and objectives. So we have to consider many variables. But program using mathematical programming method can not find the optimal solution of many variables. But industrial problem has many cases that the number of that product is bigger than that limit. Overcome this boundary, heuristic method or evolutionary algorithmic methods were proposed.

Studies about these topics includes artificial intelligence, combinatorial optimization, genetic algorithms, neural network, tabu search and simulated annealing. We can refer the review of Glover and Greenberg(1989). We are going to solve scheduling problem with simulated annealing (SA).

Certain types of optimization problems that have a lot of variables and constraints have the characteristic that the scope of the solution increases exponentially as the increase of the variable number. And it is called *NP-hard* or *NP-complete*. Heuristics was at first used for these cases. Experience and solution analyses were developed to heuristics. The development of heuristic from the experience was to apply the special features of the problem structure. On the other hand, algorithmic methods imitate or compare with the natural phenomena. SA is no exception. SA can be applicable to the very large-scale optimization problem that has great interest recently.

3.2 Previous Works of SA

The first approach is Kirkpatric *et al*(1983). The fundamental of the SA came from the similarity of the thermodynamics. The starting point of the SA is Monte-Carlo simulation- physical annealing is the model of Monte-Carlo simulation, and approached firstly by Metropolis *et al*(1953) to simulate the set of atoms at the given temperature. He calculated the energy difference of the system from the repeated exchange of places of the atoms to remain in the stable conditions. If the energy difference is below zero, the change is accepted, otherwise it is only accepted by the chance from the function of the temperature and boltzmann constants. Iteration of this following causes the system in thermal equilibrium. This acceptance function proposed by Metropolis induces the object function to have the boltzmann distribution.

He applied it to the famous traveling salesman problem(TSP) it is the general form of the NP-complete problem. And he got the good results with it, and layout of very large-scale integrated circuit design. It was used for deciding whether design suggested by heuristic can be more initiated or not. Theoretical field was based on the Markov chain

Ku and Karimi(1991) was the first used SA in scheduling problem. Their objective was the minimization of completion time under UIS policy. And Patel *et al*(1991) used SA for preliminary design of multiproduct process. Tandon *et al*(1995) presented methodology for scheduling of multiple products on parallel units with tardiness penalties with SA.

3.3 Theoretical Background

The general way for the optimization problem is whether to use the dig & conqueror search or iterative method.

While the simple descent algorithms cannot get out of local optimum, SA can escape from the limited local optimum by the 'statistically' acknowledging the minimum value.

표 1. 통계 역학과 최적화 문제의 유사성

Table 1. Analogy between the molecular statistics and optimization problem

Molecule	Optimization
Energy	Objective function
Molecule	Position variable
Ground state	Global optimum

It got the idea from the annealing of metal process with the molecule energy and allocation. SA was proposed to reform the above disadvantage of the descent algorithm. For the move to get the one initial to the better solution, you have to find a way to get away from the local optimum, and that is called the *uphill movement*. but it can not be applicable to every case. It depends on only the random variable between 0 and 1, which we determine to accept or reject move though it is not the optimal.

The basic simulated algorithms can be like this form

```
SELECT an initial state I ∈ S;
   SELECT an initial   temperature T >0;
SET temperature   change counter t=0;
   repeat
   GENERATE STATE   j a   neighbor of I
   calculate δ = f(j) - f(I)
     if  δ ≤ 0   then I:= j;
     else if random(0,1) < exp(- δ /T) then   I := j;
   n :=n+1;
   until n = N(t);
   t := t+1;
   T :=T(t);
   until stopping criterion true
```

'Statistically' is that the difference from each repetition is decided to be accepted or rejected from the comparison with normal distribution of 1 and 0 and exponential function.

If the random number is bigger than difference, we accept the move, otherwise it is rejected and new search finds the next value. The problem of difficulty is to define the value deserving to the boltzamn constant in the metal annealing and to decide the initial value to minimize the move iteration.

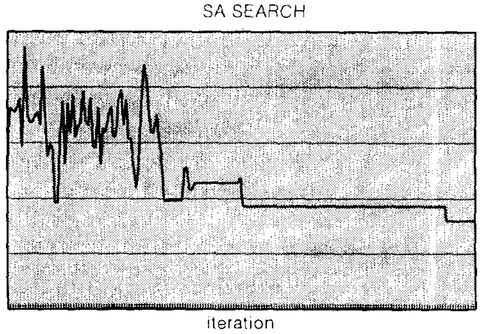

그림 4. SA를 이용한 목적함수의 최소화 변화량

Fig. 4 Perfomance of SA in objective function

3.5 application of SA in scheduling

To solve scheduling problem with SA, some modification is essential. At first, the objective function value is the due date penalty value, the solution is the sequence of products which is variables. For UIS and NIS policy, the sequence only determines the performance of schedule. And temperature(t) and boltzmann(k) constants should have to be decided with jointed value kt. kt is only affected by the penalty value differentiation that we randomly generate for enough times - about 3000 times for 8 variables. And the absolute middle value of difference of this generation is the kt value. Efficient way to find optimal sequence in short time may start from many initial sequences and compare it repeatedly. But more efficient way to decide t and k will have to be developed .

Fig.4 shows the performance of SA in scheduling problems.

4. Example

To plan the optimal production schedule for our goal means to set two conditions. One is to find the production sequence and the other is to find the operating time - starting time, ending time, and holding time etc by that sequence. And for the first one, the instant idea is to array the products by their due date. And each product is produced first due first go principle. But as we will show in the next section, *first-in-first-out*(FIFO) is not always the optimal production planning

We take example for 8 product 10 stage. It was solved at first simulated annealing method and it was confirmed by the enumerative method for the validity of solution. We could find the solution of both method produces same results.

4.1 UIS (I)

7 product 5 stage scheduling problem is solved. Case 1 is the fixed due date, and case 2 is the result of due date period application

Case	Optimal Sequence
1	2→4→1→3→6→7→5
2	1→4→2→3→6→7→5

4.2 UIS (II)

To compare with *FIFO*(First in First Out) policy, we get the following result which indicate the FIFO is not always the optimal sequence.

Case	Optimal sequence
FIFO	1→2→3→4→5→6→7→8
Point	2→1→3→6→5→8→4→7
Period	2→1→3→4→6→5→8→7

4.3 NIS

Case	Optimal sequence
Point	4→5→1→2→8→6→7→3
Period	4→5→1→2→8→6→3→7

We can find out from example solutions that by selecting due date period instead of fixed point due date, some schedule gives same penalty values but the completion time is not same. So we take optimal solution as minimum completion time.

Conclusion

Our research shows that due date minimization method is the customer oriented scheduling policy while completion time minimization is producer oriented scheduling way.

We suggest scheduling system that can handle flexible due date and flexible customer requirement. It can be possible by using the concept of due date penalty minimization and due date period. It is the more advanced production policy from taking due date as fixed point. We find the solution using SA for SA has the advantage of finding good solution in multivariable NP-complete problem in short computational time.

Acknowledgement

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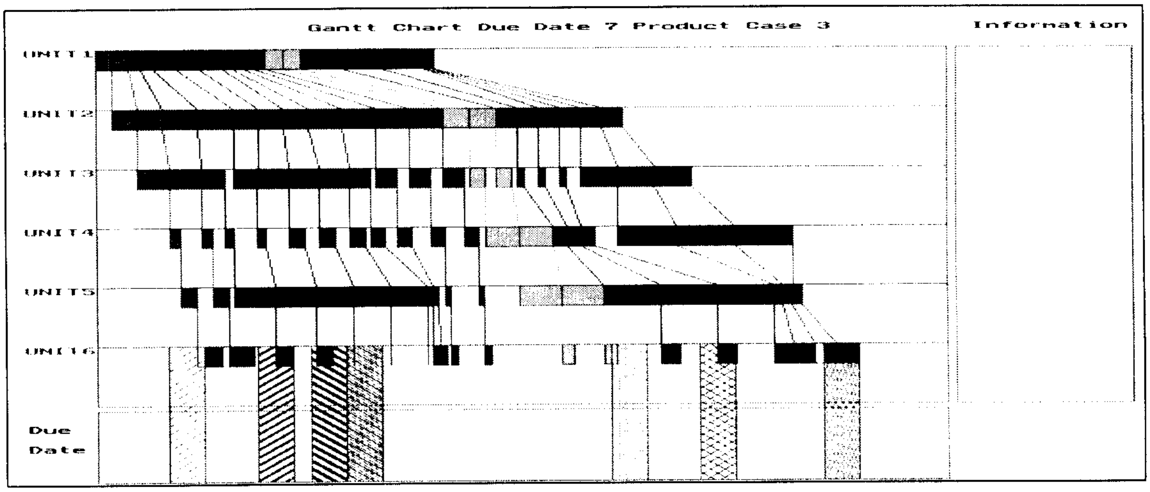

그림 5. UIS 생산 방식에서의 공정 시간 분포표(Gantt-Chart)

Fig.5 Gantt- Chart of Single product campaign under UIS policy