Integrated scheduling model for PVC process

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Abstract: In a large-scale chemical plant, there are scheduling problems in inventory and packing process although production process is stabilized. The profit of the plant is restricted by these problems. In order to improve these problems, integrated scheduling model, which is concerned with whole processes from production to shipment, has been developed in this paper. In this model, decision variables are production sequence, silo allocation, amounts of bulk shipment and packing amounts. In case of a real plant, it is hard to solve by deterministic methods because there are too many decision variables to solve. In this paper, genetic algorithm is presented to solve a PVC process scheduling model within an hour with PCs.

Keywords: Scheduling, genetic algorithm, integrated model and PVC

1. INTRODUCTION

Poly Vinyl Chloride (PVC) has been one of the important polymers for both domestic and global market. As shown in table 1.1, large amount of PVC is traded in global market and PVC is produced in many chemical companies. In these days, PVC production techniques are well developed thereby stabilizing PVC productions.

Table 1.1 PVC market

(ton)

	1999	2000	2001
Domestic market	1,160,000	1,187,000	1,236,000
Global market	26,004,000	27,208,000	28,689,000

The export-import bank of korea, 2001

However, domestic and global markets of PVC are very flexible and PVC products are traded as various types that are depending on grades, packing types and customers. Owing to limited capacities of silos and packing machines compared with large capacities and various products types of PVC production, it is necessary to manage inventory systems concerned with silo, packing and shipment.

In contrast with the manufacturing industry, which most of scheduling studies are concerned with, it is hard to schedule the process industry because continuous and batch units are mixed and fluid dynamics and complex reactions are concerned in the process industry. Nevertheless some researchers studied scheduling problems of chemical processes, one of equipment processes [1-7]. However most of these studies deal with common chemical processes and these focus on production sequencing. In order to apply to PVC processes, inventory management and specific problem of PVC processes are considered additionally.

Integrated production-inventory models are applied to common manufacturing processes [8-9]. Equation production quantity (EPQ) model is used to these processes. However there are so many decision variables in real chemical plant, it is hard to solve the integrated model in reasonable time. To resolve this problem, stochastic methods instead of deterministic methods are used. In these days, genetic algorithm (GA), one of stochastic methods, is commonly used in these problems. GA was invented and developed by J. Holland and his associates in the 1960's and 1970's. It is a stochastic, discrete event, and nonlinear process, and has been used on machine learning, artificial intelligence, pattern recognition and operation research, etc [10]. There also are some papers which discuss applications of GA to scheduling problems [10-13].

In this study, an integrated model which is concerned with production, inventory, packing and shipment has been developed and then the model has been solved by genetic algorithm.

2. WHAT ARE GENETIC ALGORITHMS?

Genetic algorithms (GAs) were invented and developed to mimic some of the process observed in natural selection, initially by J. Holland and his associates at the University of Michigan in the 1960s and 1970s. GAs use a direct analogy between the representation of a complex structure by means of a vector of components, and the idea, which is familiar to biologist, of the genetic structure of a chromosome. The chromosome is a series of bits made of the juxtaposition of varying length bit strings coding on parameters. Throughout genetic evolution, starting from a population of chromosomes, which can be randomly set initially or determined by other heuristic methods, some fitter chromosomes have the tendency to yield good quality offspring which means a better solution to the problem. Some evolution rules will be applied in order to arrive at a population that is more appropriate. To further illustrate the operational procedure, the following paragraph illustrates the logical structure of a GA.

1. Initialize a population of individuals.
2. Evaluate all individuals of the population.
3. Select a sub-population for offspring production.
4. Create new offspring by mating current sub-population.
   A. Recombine the chromosomes of the current sub-population by crossover operator.
   B. Perturb the mated population stochastically by mutation
5. Delete members of the parents' population to make room for the new individual.
6. Evaluate the offspring individuals created.
7. Select the new individuals and insert them into the population.
8. If the stopping criteria are met, stop and return the best individual; else restart at step 2.

It is necessary to define an evaluation function for each chromosome, which is the link between GAs and the objective problem. Evaluation functions play in GAs a role exactly similar to what environment plays in natural evolution. The evolution is performed by two genetic operators: the crossover operator and the mutation operator. Crossover operator acts to combine building blocks of good solutions from diverse chromosomes. The reproduction mechanisms together with crossover cause the best scheme to proliferate in the population, combining and recombining to produce high-quality combinations of scheme on single chromosomes. It is the genetic workhorse, a high-performance search technique that acts rapidly to combine what is good in the initial population and that continues to spread good schema throughout the population as a GA runs. Mutation operator will randomly hit one bit in the chromosome and flip it. In fact, the mutation is merely a device for reintroducing diversity into the population when a bit has accidentally taken on a single value everywhere. It prevents the solution from converging to some local optimal solutions; thereby the solution approaches the global optimal solution. The size of population, the rate of crossover and mutation operator and the maximum generations are chosen as the control parameters. Their settings are critically dependent upon the nature of the objective function [10].

3. TARGET SYSTEM (PVC PROCESS)

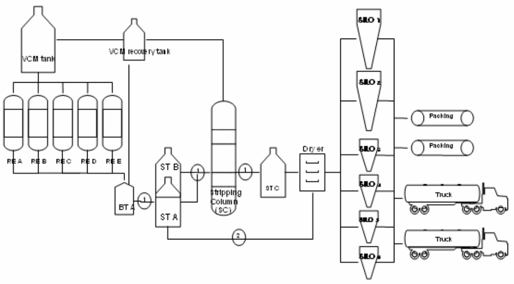

Fig 3.1 Flow diagram for PVC process

A flow diagram for the PVC process in this study is shown in Fig 3.1. The overall PVC production process can be divided into two parts: A batch part and a continuous part. The batch part of the process consists of a number of batch reactors (RE) in parallel and one blow down tank (BT). The total processing time of each reactor includes set-up time, transfer time, polymerization step and cleaning time. The grades of polymers are specified in the polymerization step and are caused by the additives. Since a lot of water is used for sealing and quenching the reactors, the removal of the water is needed in the next operations. The materials finished in the reactors are processed as slurry state in BT, the slurry tank A, B, C ($ST_{A,B,C}$) the stripping column (SC), dewaterer, dryer and in the silo the state is regarded as the powder, that is solid. The processing time of BT is also composed of the transfer time, cleaning time and retaining time for product verification. Once BT is given the material which has been finished the polymerization from one reactor during the transfer time, BT retains those materials during constant time to verify the quality of product and then those passed the test are transferred to the slurry tank during the transfer time. The slurry tank (ST_A, ST_B) serves as a buffer tank connecting the units operated in the batch mode with the units in the continuous mode by getting the products in the batch mode from the blow down tank and giving those continuously to the stripping column.

The stripping column (SC) is used to separate unreacted VCM from the product PVC. The dewaterer and dryer are used to remove the remaining water which was injected in the reaction step. The dewaterer and dryer can be thought as one unit because the dewaterer is coupled with the dryer and the role of the two units is similar. Since SC, dewater and dryer are operated in steady state after start-up period, the flowrate of those units can be considered as constant. Consequently, the processing time of continuous units are constant.

There are 4~10 silos to store products in a PVC process. In each silo, PVC is stored and then shipped as bulk type. Between silos, PVC products can be transferred to each other. For one silo, only one grade can be stored at the same time. PVC can be shipped as three types, bulk, F/C and paper bag. As mentioned in the previous paragraph, bulk type of PVC is shipped by tank lorry. F/C and paper bag is packed through packing machines connected with silos. Packing capacities and operating time of packing machines are limited. Packed products are stored in open-air storage which has unlimited capacity.

Demands are divided into two kinds, which are domestic and export demand. In case of export demand, only packed products are ordered. Ordered export demands are stored in the warehouse of the port and then exported.

4. MODEL FORMULATION

4.1. Assumptions

1. Production rate of PVC is constant.
2. Raw materials are supplied sufficiently from the VCM process.
3. Demands of PVC market are enough to cover the production capacity.
4. Orders of bulk shipments can be controlled by the PVC plant.

4.2. Operating rules

1. Setup times between successive time interval producing different products are considered.
2. Silo cannot be charged simultaneously by different grades.
3. Only products of connected silos can be packed in packing machines.
4. Different grades cannot be packed in a packing machine simultaneously.
5. Bulk shipment and packing cannot be operated in a silo simultaneously.
6. Demand types of each grade are domestic and bulk (Type I); domestic and packing (Type II); and export and packing (Type III).

4.3. Objective function

The objective of this problem is to maximize the profit of PVC plant. The total profit of PVC production can be expressed as the subtraction of penalty cost and raw material cost from sales of PVC. The penalty cost consists of the delay penalty and the inventory penalty. Delay penalty deals with tardiness cost for three product types. In inventory penalty, inventory cost of products which are stored in silos, open-air storage, and warehouse of harbor.

Therefore, the objective function can be expressed as follows:

Profit = sales revenue - raw material cost - delay penalty - inventory penalty

$$Max \quad \text{Profit} = \sum_{i=1}^{I}\sum_{j=1}^{J}(Pc_j - Pc_{J+1})Q_j X_{ij} - \sum_{m=1}^{3}\left(DeC_m + InvC_m\right)$$

$$InvC_1 = \alpha_1 \sum_{j=1}^{J}\sum_{i=1}^{I} I_{ij} Pc_j$$

$$InvC_2 = \alpha_2 \sum_{j=1}^{J}\sum_{i=1}^{I}\left[Pc_j \times Max\left\{ \sum_{l=1}^{i}\left(Rp(Cp_{lj} - C_{l-1}) - D_{lj2} - D_{lj3}\right), 0 \right\}\right]$$

$$InvC_3 = \alpha_3 \sum_{j=1}^{J} \sum_{i=1}^{I} Pc_j D_{ij3} Xs1_{ij}$$

$$DeC_1 = \alpha_4 \sum_{j=1}^{J} \sum_{i=1}^{I} \left[Pc_j \times Max\left\{ \sum_{l=1}^{i} \left(D_{lj1} - Xb_{ljk} Rb \right), 0 \right\} \right]$$

$$DeC_2 = \alpha_5 \sum_{j=1}^{J} \sum_{i=1}^{I} Pc_j D_{ij2} Xs2_{ij}$$

$$DeC_3 = \alpha_6 \sum_{j=1}^{J} \sum_{i=1}^{I} \left[Pc_j Xs1_{ij} \sum_{l=1}^{i} \left(D_{lj3} - Rp(Cp_{lj} - C_{l-1}) \right) \right]$$

Xs1 and Xs2 mean tardiness checks for Type II and Type III demands. If Type III demands of product j are satisfied at time interval i, Xs1 is 1. Otherwise Xs1 is 0. In the same way, Xs2 is 1, if Type II and Type III demands are satisfied simultaneously.

$$Xs1_{ij} = \begin{cases} 1, & \text{if } D_{ij3} \sum_{l=1}^{i} \left(D_{lj3} - Rp(Cp_{lj} - C_{l-1}) \right) > 0, \\ 0, & \text{otheriwse.} \end{cases}$$

$$Xs2_{ij} = \begin{cases} 1, & \text{if } D_{ij3} \sum_{l=1}^{i} \left(D_{lj2} + D_{lj3} - Rp(Cp_{lj} - C_{l-1}) \right) > 0, \\ 0, & \text{otheriwse.} \end{cases}$$

4.4. Production rules in production process

By assumption 1, whole production process is dealt as a unit. In time interval i, only one product j can be produced.

$$\sum_{j=1}^{J} X_{ij} = 1$$

Between successive time intervals producing different products, setup times are considered.

$$C_{i+1} - C_i - \sum_{j=1}^{J} (Pt_j \times X_{i+1,j}) \ge St - U\left(2 - \sum_{j=1}^{J} \left| X_{ij} - X_{i+1,j} \right| \right)$$

$$C_{i+1} - C_i - \sum_{j=1}^{J} (Pt_j \times X_{i+1,j}) \ge 0$$

4.5. Mass balance equations in silos

Volume of product j in silo k in time interval i = volume of product j in silo k in time interval i-1 + amount of product j produced and stored in silo k in time interval i – amount of product j shipped as bulk type in time interval i from silo k - amount of product j packed in time interval i from silo k.

$$I_{ijk} = I_{i-1,jk} + Q_j X_{ij} XI_{ijk} - Rb \times Xb_{ijk} - Rp \times (Cp_{ijk} - C_{i-1})$$

$$0 \le I_{ijk} \le IU$$

Cp_{ijk} are continuous variables between C_i and C_{i-1}.

$$C_{i-1} \le Cp_{ijk} \le C_i$$

Same product can be stored in several silos. If products are not stored in a silo, packing and bulk shipment cannot be operated.

$$XI_{ijk} = \begin{cases} 1, & \text{if } I_{\text{ijk}} > 0, \\ 0, & \text{otheriwse.} \end{cases}$$

$$XI_{ijk} \ge \frac{Cp_{ijk} - C_{i-1} + Xb_{ijk}}{U}$$

Total number of silos in which product is stored is limited.

$$\sum_{j=1}^{J} \sum_{k=1}^{K} XI_{ijk} \le Ns$$

4.6. Operating rules for packing machine

By Operating rules 3 and 7, packing and bulk shipment are operated separately.

$$Z_{ikl} = \begin{cases} 1, & \text{if } Cp_{ijk} > C_{i-1}, \\ 0, & \text{otheriwse.} \end{cases}$$

$$\sum_{j=1}^{J} Xb_{ijk} + \sum_{l=1}^{L} Z_{ikl} \le 1$$

Packing machine can be used for connected only one silo.

$$\sum_{k' \in C_l} Z_{ik'l} = 1$$

5. APPLICATION OF GA TO PVC PROCESS

The proposed GA approach is described in detail in the following sections.

5.1. Gene representation

Traditionally, chromosomes are simple binary vectors. This simple representation has an appeal, and the theoretical grounding of GAs is based on binary vectors and simple operators.

In this study, silo allocation, bulk shipment and packing amounts as well as production sequencing are decision variables. As mentioned in chapter 2, decision variables are represented as a binary vector.

5.2. Initial population production

The population initialization technique used in the proposed GA approach is a random binary variable generation which creates a starting population filled with randomly generated binary-value strings.

5.3. Evolution and fitness

Evaluation function plays in GA a role similar to that which environment plays in natural evolution. Sometimes the best and the worst chromosomes will produce almost the same numbers of offspring in the next population and the premature convergence is caused. In this case, the effect of natural selection is therefore not obvious. In the proposed GA approach, the objective function is considered as the evaluation rule of every individual. A nonlinear normalization, which converts the evaluations of chromosomes into fitness values, is used here to avoid its premature convergence. This technique is described in the following equations. N is the population size. *f* is the fitness value and *g* is the objective value.

$$f_i = \frac{1}{1 + \exp\left(-\beta \frac{g_i - g_{mean}}{g_{\max} - g_{\min}} \right)} \qquad i = 1, 2, \cdots, N$$

5.4. Parents selection and genetic operators

The purpose of parent selection is to give more reproductive chances to those population members which are the fittest. A commonly used technique, roulette-wheel-selection, which is illustrated in following the paragraph, is used in the proposed GA approach.

Roulette-wheel-selection algorithm

Step 1. Sum of fitness of all the population members,

$$F_{total} = \sum_{i=1}^{N} f_i$$

Step 2. Initialize, index $i = 0$ and a counter $F = 0$,

Step 3. Randomly generate a real number $f \in [0, F_{total}]$

Step 4. $i = i + 1,\ F = F + f_i$

Step 5. If $F \geq f$, then return selected position i and stop; else go to step 4.

Genetic operators used to perform evaluation are crossover operator and mutation operator. Crossover is an extremely important component of GA, which makes GA different from all other conventional optimization algorithm. It can recombine the parents and produce offspring, such as the new individuals. It is executed by exchanging the same parts of gene-codes between two individuals. Two-point crossover is used in the proposed GA approach.

Mutation is used as the genetic operator in the proposed GA, which reintroduces diversity into the population when a bit has accidentally taken on a single value everywhere. It prevents the solution from converging to some local optimal solution and approaches the global optimal solution. The commonly used technique, which is illustrated in following paragraph, is used in the proposed GA.

Step 1. Generate random number r between [0,1],
Step 2. If $r<P_m$, then operate mutate for the bit.

5.5. Selection or survival

Selection occurs for solutions showing high fitness. To avoid losing the best chromosome's genes, elitist strategy is used for this realization. [10] This strategy prevents the potential best number loss by copying the best member of each generation into the succeeding generation. It is used to speed up the convergence.

6. EXAMPLE AND RESULTS

Based on the proposed model, the problem for PVC plant, which is operated at present, has been solved. The configurations of this example and common PVC process are same. Only the number of silos, packing machines and products are varied. In this example, number of silos is five, number of packing machines is three and number of products is two. Time horizon is a month and production amount in a month is about 14,000 ton. Each product is shipped as bulk or packing type. To formulate the objective function, price data are necessary and those are shown as relative values in table 6.1.

Table 6.1 Relative prices of products and raw material

Name	Price
Product 1	1.0
Product 2	1.1
Raw material	0.6

In the real plant, product 1 is produced for five days and product 2 is for two days repeatedly. In this section, optimized result of production, inventory, packing and shipment is compared with real data in the same conditions.

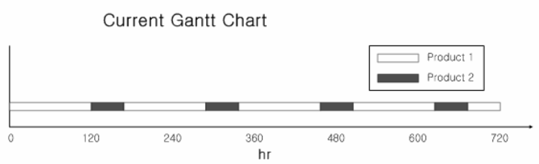

Fig 6.1 Current Gantt chart

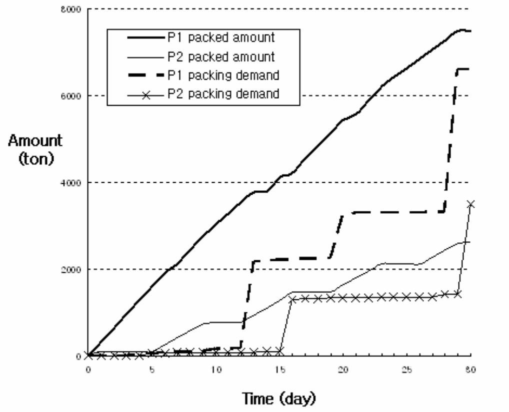

Fig 6.2 Current demand and production for bulk type

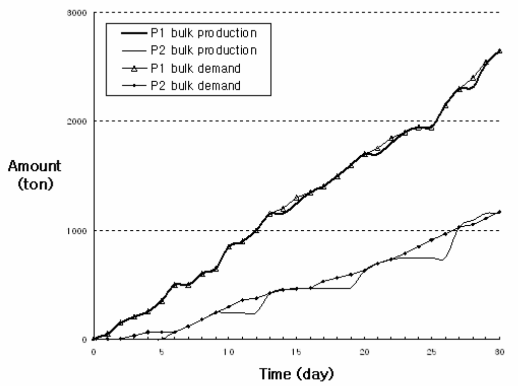

Fig 6.3 Current demand and production for packing type

Fig 6.1 shows Gantt chart for real data. As mentioned above, products 1 and 2 are produced in constant ratio. According to demand and production sequence, total shipped amount and integrated demand of bulk and packed products are shown in Figs 6.2 and 6.3. As shown in Fig 6.3, large delay penalty of packing product is expected at the end of the time horizon. It is expected that this penalty affects the profit and optimized results lead to reducing this penalty.

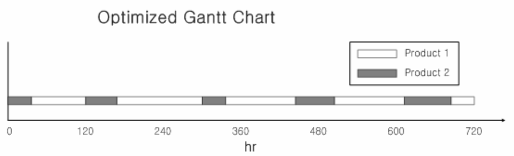

Fig 6.4 Optimized Gantt chart

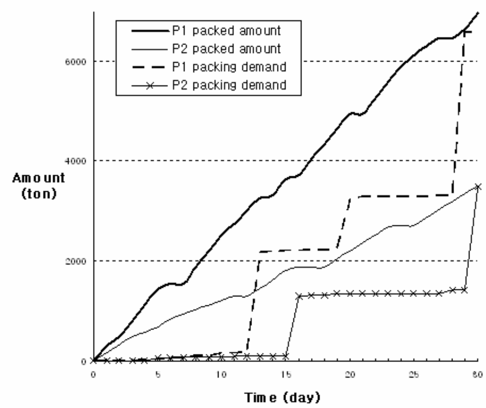

Fig 6.5 Optimized demand and production for bulk type

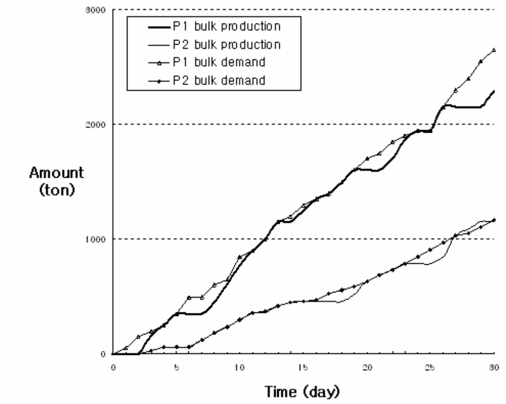

Fig 6.6 Optimized demand and production for packing type

Optimized results are shown in Figs 6.4~6. Fig 6.4 shows Gantt chart for optimized results. And the total shipped amount and the integrated demand of bulk and packed products are shown in Figs 6.5 and 6.6. In Fig 6.5, it is shown that the mentioned delay penalty is reduced.

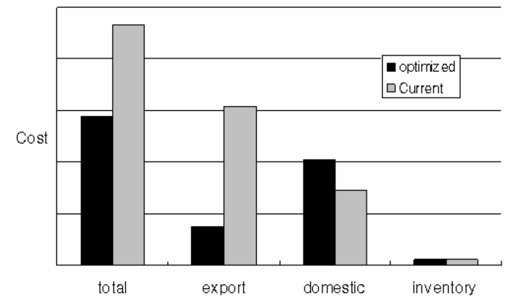

Fig 6.7 Penalty analysis

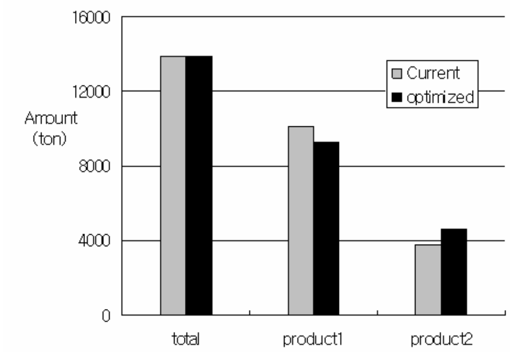

Fig 6.8 Comparison of production amounts

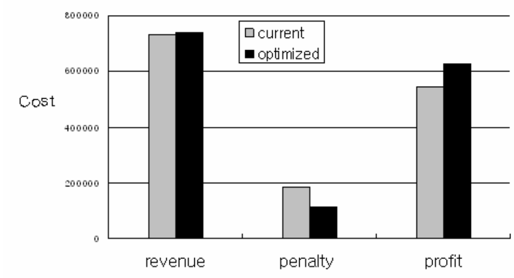

Fig 6.9 Comparison of profit

To analyze the profit, analyses for revenue and penalty cost are shown in Figs 6.7~9. As shown in Fig 6.7, export delay penalty is reduced by reducing tardiness. Fig 6.8 shows that production amount of more valuable product, product 2, increases at optimized results and revenue also increases. Consequently as shown in Fig 6.9, the profit increases about fifteen percent. However in real situations, the process can not be operated exactly in optimized conditions. Therefore the effect of optimization can be reduced less than fifteen percent. In Figs 6.10~12, comparisons of data are shown.

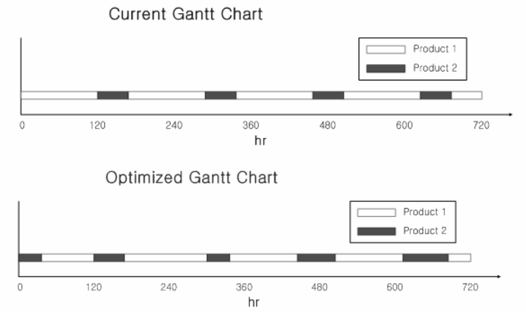

Fig 6.10 Comparison of Gantt charts

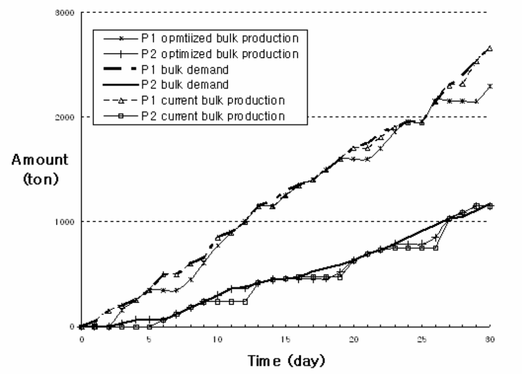

Fig 6.11 Comparison of demand and production for bulk type

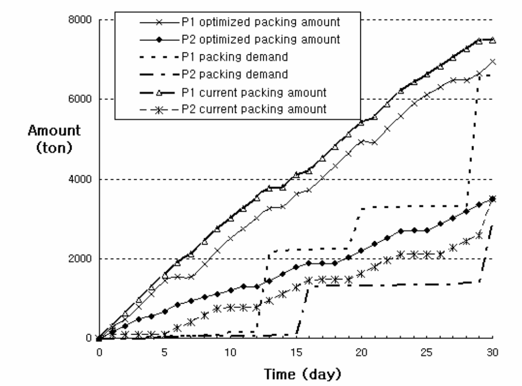

Fig 6.12 Comparison of demand and production for packing type

7. CONCLUSION

An integrated scheduling system which is concerned with PVC production, inventory, packing and shipment has been developed and then this model is solved by genetic algorithm. As a result, compared with the current operation the profit increased about fifteen percent. In our country there are scores of PVC plants that have the same configuration. This study will be helpful to optimize other PVC plants. Furthermore, this model will be the basis for optimizing the whole process optimization including VCM process.

ACKNOWLEDGMENTS

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NOMENCLATURE

Indices

i = time interval
j = product
k = silo
l = packing machine
m = product type
1 = domestic and bulk
2 = domestic and packing
3 = export and packing

Variables

C_i = Completion time at time interval i
Cp_{ijk} = Actual packing completion time of product j of silo k in time interval i
DeC_m = Delay penalty cost for product type m
I_{ijk} = Volume of silo k
$InvC_m$ = Inventory cost for product type m
X_{ij} = binary variable to denote if product j is produced in time interval i
Xb_{ijk} = binary variable to denote if product j is shipped as bulk type from silo k in time interval i
XI_{ijk} = binary variable to denote if product j is stored in silo k in time interval i
$Xs1_{ij}$ = binary variable to denote if total shipped amount of product j in time interval i is satisfied Type III demand
$Xs2_{ij}$ = binary variable to denote if total shipped amount of product j in time interval i is satisfied Type II and Type III demands
Z_{ikl} = binary variable to denote if product of silo k is packed through packing machine l

Parameter

D_{ijm} = type m demand of product j in time interval i
Ns = total number of silo
Pc_j = price of product j
Pc_{J+1} = price of raw material
Pt_j = processing time of product j
Q_j = production amount of product j of each time interval
Rb = bulk shipping rate from silo
Rp = packing rate of packing machine
St = setup time

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