

3. Modeling for scheduling

A mathematical model for PVC scheduling can be formulated through MILP (Mixed Integer Linear Programming). Operation rules which are used during real processes were applied to the mathematical model.

The objective of this model is the maximization of profit; this can be formulated by (1).

$$\text{Profit} = \text{Sales} - \text{Raw material cost} - \text{Demand delay cost} - \text{Inventory cost} \quad (1)$$

More detailed mathematical formulation is derived in [11]. The mathematical model incorporated entire process including; production, inventory management, packing and shipment.

4. Solving algorithm

During the last decade, scheduling problems have become increasing by more complicated due to various attempts to solve complex, real-world problems. Several hybrid systems have been proposed to help solve these complex problems, these have emerged as useful tools. One such system is the hybrid system, which integrates GA and LP [4~7]. The background of GA and LP are presented in sections 4.1 and 4.2. Section 4.3 describes the algorithm used to solve the proposed scheduling model.

4.1 Genetic algorithm

Genetic algorithms (GAs), which have been developed by John Holland, his colleagues, and his students at the University of Michigan, are search algorithms based on the mechanics of natural selection and natural genetics. They combine the idea of survival of the fittest amongst string structures with a structured, yet randomized, information exchange. This forms a search algorithm maintaining some of the innovative flair associated with a human-based search. In every generation, a new set of artificial creatures (or strings) is created using bit and pieces of the most fit of the old strings; an occasional new part is also tried for good measure. GAs have been found to efficiently exploit historical information in order to speculate on new search points, which have an expected improvement in performance.

GAs primarily include reproduction, crossover, and mutation processes. Reproduction is a process in which individual strings are copied according to their objective function values. Copying strings according to their fitness values implies that strings with a higher value will have a higher probability of contributing one or more offspring in the next generation. After reproduction, crossover may proceed in two steps. In the first step, members of the newly reproduced strings which exist in the mating pool are mated at random. Secondly, each pair of strings undergoes crossing over. Mutation is defined as the occasional random alteration; this has a small probability of occurrence in strings.

GAs are different from other optimization method in four ways. First, GAs work with a coding of the parameter sets, not with the parameter themselves. Second, GAs search from a population of points as opposed to a single point. Thirdly, GAs use payoff information instead of derivatives or other auxiliary knowledge. The fourth difference is that GAs use probabilistic transition rules instead of deterministic rules. These four differences contribute to a genetic algorithm's robustness, showing an advantage over other, more commonly used

techniques [8].

In this study, X_{ij} are optimized by use of genetic algorithms.

The other variables are optimized through use of linear programming (LP), this is described in section 4.2.

4.2. Linear programming

The scheduling model possesses a NP-hard problem since it includes integer variables, X_{ij} . However, this model will

become a polynomial problem through use of LP, after X_{ij}

are fixed by GAs. At this point, only Cb_{ijk} and Cp_{ijk} are decision variables in LP. We use the interior point method in order to achieve a 'good' solution of this LP model within a reasonable amount of time. In this LP model, the interior point method is more efficient than the simplex method. This is due to the existence of numerous basic feasible solutions that can be solved by the simplex method. Also, it is very difficult to transform this LP model into the standard form required for the simplex method.

4.3. Algorithm

Deterministic methods and stochastic methods are both used for optimization of the MILP model. Employment of genetic algorithms as a stochastic method is used for the integer portion of the model. The interior point method, defined as a deterministic method, is used for optimizing the continuous variables. However, there are too many variables to optimize with this approach in a reasonable amount of time. In order to improve upon this problem, a method which can reduce the search area of the genetic algorithm is needed. Using only a production sequence, the lower bound of demand penalty (LBD) can be calculated with the use of equation (25). Using the LBD value, the upper bound of the objective value (UBO) for the production sequence can be estimated, this is done with equation (26). This means that the objective value for the production sequence can not exceed the UBO. Optimization for continuous variables is not needed for the production sequences where the upper limit is lower than the highest objective value.

$$\begin{aligned} \text{Objective value} &= \text{Sales} \\ &- (\text{Demand penalty} + \text{Inventory penalty}) \end{aligned} \quad (24)$$

$$\text{Demand penalty} + \text{Inventory} \geq \text{LBD} \quad (25)$$

$$\text{UBO} = \text{Sales} - \text{LBD} \geq \text{Objective value} \quad (26)$$

This approach makes it possible to reduce the number of iterations for LP optimization; consequently a good solution for the PVC scheduling problem can be obtained within a reasonable time period.

In order to get the global optimum values of integer variables and continuous variables, genetic algorithms and gradient based algorithms must operate simultaneously as shown in the following process:

- Step 1. Create feasible solutions of X_{ij} as the population of the first generation.
- Step 2. Solve the LP of Cb_{ijk} and Cp_{ijk} .
- Step 3. Evaluate the fitness value.
- Step 4. Check the termination criteria. If yes, go to Step 8. Otherwise continue with Step 5.
- Step 5. Reproduce feasible solutions of X_{ij} to be the population of the next generation.

- Step 6. Evaluate the UBO of the feasible solution of X_{ij} .
- Step 7. Select a feasible solution with the UBO. Then go to Step 2.
- Step 8. Terminate.

5. SYSTEM DEVELOPMENT

The developed system consists of three components; Data base, GA engine, and Graphic User Interface (GUI). ERP system for the PVC plant is used as a data base. GA engine is developed by the mathematical model and the proposed optimization approach as mentioned in section 3 and 4. GUI is developed based on EXCELTM. EXCELTM is one of most widely distributed commercial and its interface is very familiar with the operators of PVC plant.

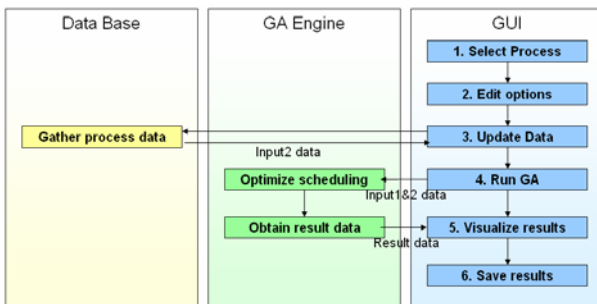


Fig 2. A flow diagram of the developed system

Fig 2 shows the flow diagram of the PVC scheduling system. The flow is consists of six steps as following.

The screenshot shows a spreadsheet-like interface for process input. It includes buttons for '입력' (Input), '버튼' (Button), and '완료' (Complete). The input fields are organized into sections: 'Process setting' (including number of silos, number of grade, yields of grades, etc.) and 'Process configuration' (between silos and packing machines). The interface uses a grid system with columns labeled NS1, NMAP, NMAP, and NJ2.

Fig 3. Process input window

Step 1 Select process. By selecting a process, detailed input options; the number of grades, the number of silos, the number of packing machines, the yields of grades, the maximum capacity of each silo and the connected configuration of silos and packing machines are decided by its default value. In order to communicate between three components of this system, text files are used. The number of input files for the GA engine is two and the number of output files is five. One of input files has the information which depends on the process. That is input options shown in Fig 2.

Step 2 Edit option. Decided input options as the default values can be edited by user. This step can be skipped

unless the configuration of plant or the process setting is changed.

Step 3 Update data. Another input file has the information for inventory and demand. This file can be updated from D/B automatically.

Step 4 Run GA. During steps 1~3, input files for the GA engine are accomplished. The GA engine optimizes the PVC scheduling model.

Step 5. Visualize results. After the execution of the GA engine, five output files are made as the results of optimization. The output files are loaded to EXCELTM. After that, the results are visualized as graphs. As shown in Fig 4, the graphs are divided into three categories; time chart, product chart, and silo & packing chart.

Step 6. Save results.

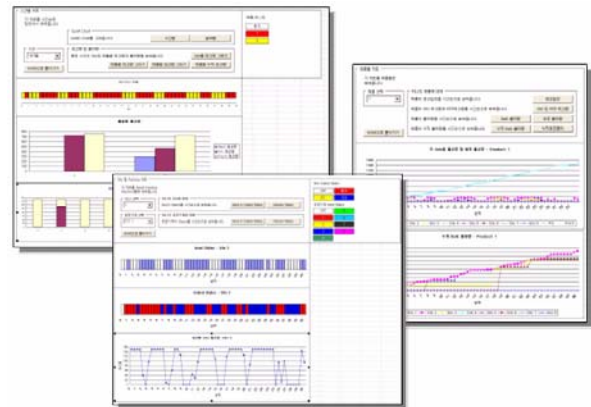


Fig 4. The optimization result graphs

6. RESULTS

The mathematical model and the proposed optimization approach were applied to two PVC production plant lines; the two production processes had different characteristics.

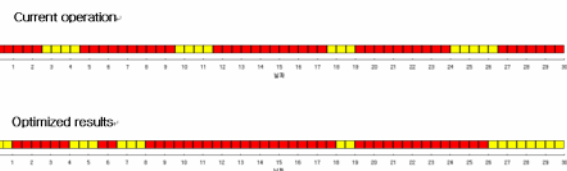
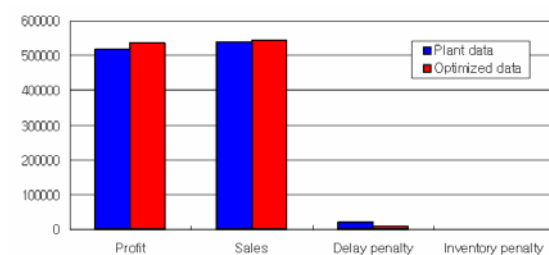


Fig 5. Comparison of the optimization results and the current operation for Process 1

Process 1 produces two grades of PVC and large orders are often placed for these grades. In this process there are 8 silos and 3 packing machines. For this test example, the demand

delay cost is considered important because the production amounts for the two grades are almost always fixed and the inventory cost is very low. Therefore, scheduling results which reduce the demand delay cost are required.

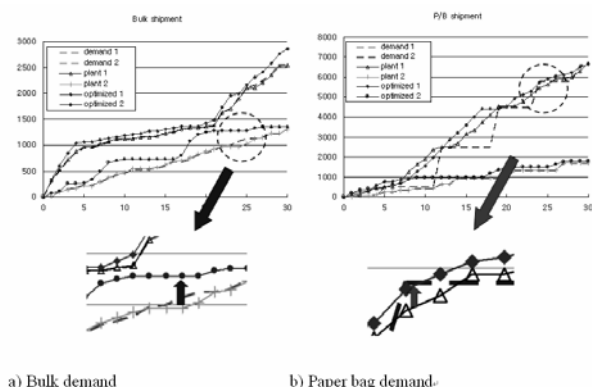


Fig 6. Reduced demand delay cost in integrated inventory and shipment amount for Process 1

As shown in Fig 5, the optimization resulted in a 4.6 percent increase of profit. This was achieved by reducing the demand delay cost and producing more expensive grades during the surplus time. Fig 6 shows integrated inventory existing in either the warehouse or silos, as well as an integrated shipment amount for Process 1. When the integrated demand is higher than the integrated inventory amount, demand delay cost is incurred. When compared with plant data and demand profiles the dotted circle represents the occurrence of demand delay cost. However, the optimized result shows that integrated inventory is higher than the integrated demand and thus the demand delay cost is reduced.

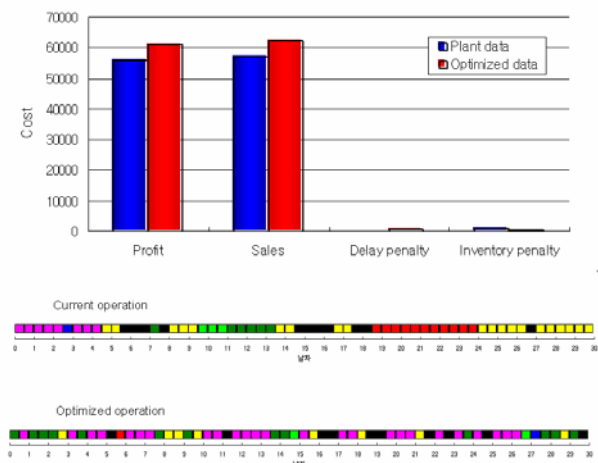


Fig 7. Comparison of the optimization results and the current operation for Process 2

As opposed to process 1, process 2 produces more than eight grades of PVC and small orders are usually placed. There are 6 silos and 4 packing machines. For process 2, total capacity of the silos is large enough to store half of the monthly production amount. However, the number of silos is less than the number of PVC grades produced. Therefore, PVC should be stored as F/C and paper bag types. Consequently, one of the important factors in this process is the inventory penalty cost.

The demand for this process is usually smaller than the production capacity. Another important factor in scheduling is the use of the surplus production capacity during PVC production. In this case, reduction in inventory costs and more efficient production were achieved by implementing the scheduling results.

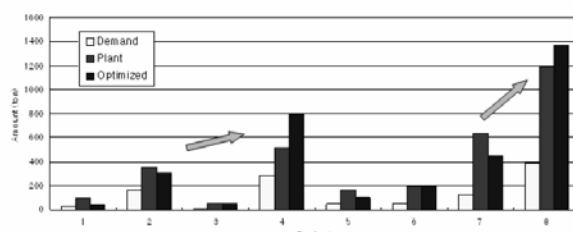


Fig 8. Production amount and demand for Process 2

As show in Fig 7, the optimization resulted in a 9.5 percent profit increase by reducing inventory cost and producing more expensive grades during the surplus time, rather than reducing the demand delay cost. Fig 8 shows the production amount of the plant data and optimized results. However, there is no guarantee that the entire amount of PVC produced is sold in the market, additionally unexpected orders can occur. Because of this it is not appropriate that only the most expensive grade should be produced, thus the safety inventory amounts should be maintained. Fig 8 shows the optimized production amount for the safety inventory.

7. CONCLUSION

In this study, a scheduling system based on a mathematical model and an efficient optimization algorithm has been developed. The mathematical model has been proposed for scheduling of the entire process of a PVC plant, including: production, inventory, packing and shipment. Additionally, a more efficient optimization algorithm for this model has been studied. For validation purposes, two PVC plants with different characteristics were used. The optimization results showed that the proposed mathematical model and optimization algorithm resulted in an increase of at least 4.5% in profits, obtaining good results in a reasonable amount of time; approximately 5 minutes by a 3.0 GHz PC.

The proposed model and algorithm are expected to be applicable to other PVC plants, since PVC plants typically have similar configurations. Furthermore, it is expected that these could be applied to other polymerization plants with similar configurations. Finally, we plan to integrate them with demand forecasting in order to save on the demand penalty and to produce various grades of PVC more efficiently.

8. ACKNOWLEDGEMENT

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9. REFERENCE

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