DEVELOPMENT OF PC-BASED INTEGRATED SCHEDULING SYSTYEM WITH DEMAND FORECASTING FOR PVC PLANT

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Abstract: An integrated scheduling system with demand forecasting has been developed. The SARIMA (seasonal autoregressive integrated moving average) model is automated to forecast the demand. In order to reduce the cost and instability of production scheduling, a safety inventory determination is also automated additionally. A scheduling system based on the mathematical model and the efficient optimization approach has been proposed. The mathematical model has been proposed for scheduling of the entire process of a PVC (Poly Vinyl Chloride) plant, including production, inventory, packing and shipment. Additionally, a more efficient optimization approach has been proposed. For validation purposes, a real PVC process was tested. The optimization result shows that the proposed mathematical model and optimization approach 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.

Keywords: scheduling, hybrid method, genetic algorithm, demand forecasting, safety inventory, PVC

1. INTRODUCTION

These days there are so many scheduling systems or softwares. But only few scheduling systems have succeeded in the market. Those systems have various functions and powerful optimization engine to solve scheduling problems. In spite of powerful engine and functions, those systems have difficulties to be applied to real processes. Each real process has different and various operating rules. These numerous operating rules can not be concerned in one scheduling system. Additionally, because of various functions those systems require much time to learn how to use. Therefore most of commercial systems that are already installed in real processes are not used by operators.

In order to resolve this problem, a specified scheduling system for a target process is required. It should be easy to handle and concern all operating rules of the target process. In order to develop this system, mathematical model and optimization algorithm for scheduling are required.

The scheduling results depend on input data such as amounts of inventory and demand. However demand data has uncertainties, because demand amounts depend on market and price of product. Actually it is hard to get exact demand for one-month. Furthermore, orders can suddenly occur during scheduled operations. In order to resolve this problem, an exact demand forecasting system should be proposed to get efficient scheduling results.

1.1. Scheduling model for PVC plant

Poly Vinyl Chloride (PVC) is one of major commercial polymers and it is widely utilized as a raw material of various chemical and petrochemical products. Production amount of PVC is about 300 million ton per year in the world. The PVC plant have various production processes and capacity of each process is about 10~100 thousand ton per year (Korean Petrochemical Industry Association, 2004).

There are numerous complexities to optimize such a large scale plant. It means that even trivial errors in scheduling and inventory management lead to great financial losses within the large scale plant. Consequently, there are many opportunities in PVC plants to increase profits through improvements to scheduling and inventory management.

The scheduling problem faced by PVC plants has been previously studied by only Shah et al. (1996) and Bretelle et al. (1997). A simple scheduling problem having of polymerization kinetics was studied (Bretelle et al. (1997). This study focused on the kinetic modeling and simulation. Their problem only dealt with a PVC plant conceptually. Shah et al. (1996) presented a framework of scheduling S/W development, but they didn't open the scheduling problem.

A PVC process includes batch and continuous units. Several scheduling problems of batch/continuous process have been studied (Nott and Lee, 1999; Mockus, et al., 1996; Djavdan, et al., 1992). These studies are focused on minimizing makespan or connectivity of discrete process and continuous units. But they concerns only production process. For the real scheduling problem of PVC plant, inventory and packing processes should be also concerned, because these processes affect sales, inventory cost, and demand delay cost. Therefore, in order to increase the profit of the PVC plant, the scheduling problem should deal with the entire process including production, inventory management, packing and shipment. In this study all the PVC production processes are considered to formulate the scheduling problem of PVC production.

1.2. Optimization algorithm for scheduling model

During the last decade, various attempts have been tried to solve complex and large scale scheduling problems (Luo, et al., 2001). Several efficient techniques such as mathematical programming, linear programming-based branch and bound method, and some heuristic methods have been proposed to solve large scale problems (Dahal, et al., 2001). However there are some drawbacks to solve large scale problems by these techniques. Due to curse of dimensionality (Parker, 1995), search space of mathematical programming techniques increase exponentially with size of problem. Linear programming-based branch and bound methods are poor in handling of nonlinear objectives and constraints. Other heuristic techniques generally require several assumptions to solve complex problems.

In order to overcome these limitations, GA (Genetic Algorithm) has been attempted to the complex and large scale scheduling problems. However GA requires lots of computational time to find an optimal solution. In order to solve large scale scheduling problem, hybrid optimization techniques combining GA and other method have been proposed (Luo, et al., 2001; Dahal, et al., 2001; Bierwirth, et al., 1999; Hart and Ross, 1998). The hybrid techniques are developed using efficient decoding (Bierwirth, et al., 1999), combining with heuristic (Hart and Ross, 1998; Dahal, et al., 2001), employing concept of ordinal optimization (Luo, et al., 2001).

1.3. Forecasting

Most existing forecasting systems require user's knowledge about forecasting. Therefore operators of real plants cannot use the forecasting systems when they make their production schedule. So, an automatic forecasting system which does not require user's knowledge should be developed for the efficient scheduling. For the convenience of users, the system should automatically construct data sets from raw data of D/B as well as automatic forecasting. And results of this system should be also automatically exported to scheduling system.

There are many algorithms of demand forecasting. Among these algorithms, time series models can be automated more easily, because these models can be formulated only by historical demand data (Kang, 2004).

The specific factor of time series models is organized into trend, cycle, seasonality and random factor. Methods reflecting these all factors are ARIMA (Autoregressive Integrated Moving Average) model, exponential smoothing, and artificial neural network model. But artificial neural network requires large number of data (James, 2003). The other methods, ARIMA and exponential smoothing were compared by Granger and Newbold (1974) and Reid (1975). They showed ARIMA gave more accurate out-of-sample forecasts on average than exponential smoothing although ARIMA required much more effort.

2. TARGET SYSYEM

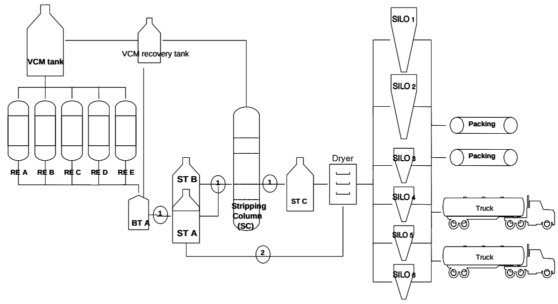

Fig 1 A schematic diagram for the PVC plant

The PVC scheduling problem includes all the PVC production units from feed tanks to packing machines. A schematic diagram of PVC plant is shown in Fig 1. The PVC plant consists of a VCM (Vinyl Chloride Monomer) tank, 5 polymerization reactors, 4 intermediate storage tanks, 2 stripping columns, 2 dryers, silos with different sizes, and packing machines.

The PVC plant can be divided into two sections: a batch section and a continuous section. The batch section consists of a number of batch reactors in parallel and blow-down tanks. Other units are continuous section.

VCM, the raw material of PVC, is supplied by the VCM plant which is directly connected to PVC plant and recovered from blow-down tanks and stripping columns in the PVC plants. The VCM is sufficiently supplied by the VCM plant. In polymerization reactors, various grades are specified by different additives. Whenever grades are changed, compositions of additives are changed and setup time is required.

Blow-down tanks and slurry tanks are used as intermediate storage tanks which are connected to the continuous units. In the stripping column, unreacted VCM is separated and recovered as the feed of the reactors. Due to the large amount of water used for sealing and quenching the polymerization reactors, the removal of the water is required in the dryer.

Produced PVC is stored in silos that are connected to the dryers. Stored PVC can be packed by packing machines and then stored in warehouse. Polymerized PVC is shipped in three ways, these are: F/C (Flacon), paper bag and bulk. Bulk type PVC is shipped from the silos directly, and the F/C type and paper bag type are shipped from the warehouse. Packed products are exported or sold in domestic market.

3. SCHEDULING

3.1 Scheduling model

According to operating rules of real PVC process, a mathematical model for PVC scheduling can be formulated as an MILP (Mixed Integer Linear Programming). The objective of this model is the maximization of profit; this can be formulated by equation (1).

Profit = Sales – Raw material cost
– Demand delay cost – Inventory cost (1)

In this model, the decision variables of this model are X_{ij}, Cb_{ijk} and Cp_{ijk}. Production sequence is determined by the binary variables X_{ij}. X_{ij} indicate whether grade *j* is produced at time interval *i*. If grade *j* is produced, X_{ij} is 1. Otherwise X_{ij} is 0. Cb_{ijk}, and Cp_{ijk} are considered to be continuous variables used to measure the amount of shipping and packing. Cb_{ijk} indicate the amount of shipped bulk of product *j* from silo *k* at time interval *i*. Cp_{ijk} indicate the packed amount of grade *j*. Cb_{ijk} and Cp_{ijk} are constrained by C_{ij} and $C_{i-1\,j}$ as follows.

$$C_{i-1,j} \le Cb_{ijk} \le C_{i,j} \qquad \forall i, \forall j, \forall k \qquad (2)$$

$$C_{i-1,j} \le Cp_{ijk} \le C_{i,j} \qquad \forall i, \forall j, \forall k \qquad (3)$$

If Cb_{ijk} is equal to $C_{i-1,j}$ in equation (2), the shipped amount of grade *j* from silo *k* at time interval *i* is 0. If Cb_{ijk} is equal to $C_{i,j}$, the product *j* is shipped with maximum shipping capacity of silo *k*. $C_{i,j}$ in equations (2) and (3) indicate the completion time of grade *j* at time interval *i*. $C_{i,j}$ can be calculated after X_{ij} are determined.

More detailed mathematical formulation is derived in (Kang, et al., 2003). The mathematical model incorporates entire process including; production, inventory management, packing and shipment.

3.2 Solving algorithm

In this study, a hybrid approach with GA and interior point method is proposed and it is applied to the PVC plant scheduling. Additionally a heuristic technique of GA is proposed to reduce number of iterations of interior point method.

The PVC scheduling model is formulated through an MILP whose decision variables are X_{ij}, Cb_{ijk} and Cp_{ijk}. X_{ij}

X_{ij} are optimized by GA. The other variables, Cb_{ijk} and Cp_{ijk}, are optimized by the interior point method. The PVC plant scheduling model includes integer variables, X_{ij} and it is an NP-hard problem. This model becomes LP, after X_{ij} are fixed by GA. After X_{ij} are fixed, only Cb_{ijk} and Cp_{ijk} are decision variables in the LP. We use the interior point method in order to achieve a 'good' solution of this LP model within a reasonable amount of time. This LP model of the PVC scheduling problem has many feasible solutions. Simplex method may not find the optimal solution among the feasible solutions or may require a lot of computational load, when the problem has many feasible solutions. Also, it is very difficult to transform the proposed LP model into the standard form which can be solved by the simplex method. In this LP model, the interior point method is more efficient than the simplex method.

This approach has many decision variables and it requires much computational load. In order to reduce the computational load, a search area reduction method of the GA is required. Using a production sequence determined by GA, the lower bound of demand penalty (LBD) can be calculated with the use of equation (5). Using the LBD value and equation (4), the upper bound of the objective value (UBO) for the production sequence can be estimated in equation (6). The objective value for determined production sequence can not exceed the UBO. When the upper limit is lower than the highest objective value in equation (6), LP optimization by interior point method isn't required.

Objective value = Sales - (Demand penalty + Inventory penalty) (4)
Demand penalty + Inventory $\ge$ LBD (5)
UBO = Sales - LBD $\ge$ Objective value (6)

This approach can reduce the number of iterations for LP optimization and consequently it can solve the PVC scheduling problem within a reasonable time.

In order to get global optimum value set, integer variables and continuous variables should be solved by genetic algorithms and interior point method simultaneously as shown in the following procedure:

Step 1. Create feasible solutions of X_{ij} as the first generation.
Step 2. Solve Cb_{ijk} and Cp_{ijk} of the LP using the interior point method.
Step 3. Evaluate the fitness value of GA.
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} as the next generation.
Step 6. Evaluate the UBO using X_{ij}.
Step 7. Select a feasible solution with the UBO. Then go to Step 2.
Step 8. Terminate.

4. DEMAND FORECASTING AND SAFETY INVENTORY

4.1 Seasonal ARIMA model

The ARIMA model is an important forecasting tool, and it is the basis of many fundamental ideas in time-series analysis. The acronym ARIMA stands for "Autoregressive Integrated Moving Average."

In many actual business situations the time series to be forecast are quite seasonal. The seasonality can cause some problems in the ARIMA process, since a model fitted to such a series would likely have a very high order. Thus seasonal terms for ARIMA model are required. A seasonal ARIMA (SARIMA) model is used, when the time series data has seasonality like the PVC products data.

4.2. Box-Jenkins process

The forecasting procedure based on the more general class of ARIMA models is often called the Box-Jenkins forecasting procedure. The Box-Jenkins process for SARIMA model of PVC plant is modified as follows.

In step of choice of difference and choice of seasonal difference, each differencing order is selected by the autocorrelation coefficient before and after differencing. The order differencing that has the least ACF (Autocorrelation function) under secondary differencing is executed. And *T-ratio* between the estimated ACF and its error is used for detection of seasonality.

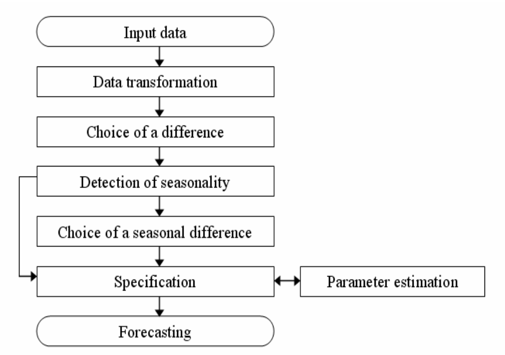

Fig 2 Diagram of automatic ARIMA modeling

In the specification step, all available models are tested by four criteria: AIC (Akaike's information criterion), SBC (Schwart's Bayesian criterion), Ljung-Box chi-squares statistics, and MAPE (mean absolute percent error). And four or less models among the candidates are selected by the four criteria. Then, forecasting abilities of the selected models are evaluated to select best model among them. Finally, the model that has the best ability to forecast is selected for forecasting. The parameter estimation is employed to carry out the part of model testing. Unconditional least square (ULS) is applied to every ARIMA model for the parameter estimation.

4.3 Safety inventory determination

The errors in the forecasted data are related to the demand forecasting method. The portion of the actual demand that is not reflected by the forecasting method creates its errors. So the future unreflected portion, error, can be forecasted by the past portion which is known as residuals. Using the absolute value of error safety inventory can be forecasted. Forecasting method for safety inventory is exactly the same as the method used for demand forecasting (Kang, 2004).

5. SYSTEM DEVELOPMENT

The developed system consists of three components; Data base, engines, and GUI (Graphic User Interface). The ERP system for the PVC plant is used as a data base. Engines consist of forecasting engine and scheduling engine. The forecasting engine is developed by Box-Jenkins process with SARIMA and safety inventory determination method which are described in section 4. The scheduling engine is developed by the mathematical model and the proposed optimization approach as mentioned in section 3. GUI is developed based on EXCEL^{TM}. EXCEL^{TM} is one of the most widely distributed commercial softwares and its interface is very familiar to the operators of PVC plant.

5.1. Execution

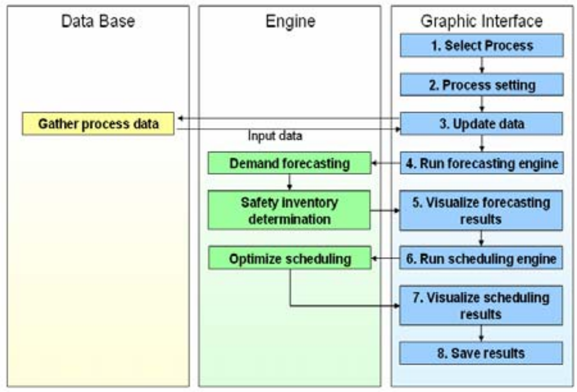

Fig 3 A flow diagram of the developed system

Fig 3 shows the flow diagram of the integrated scheduling system. The flow consists of 8 steps as following.

1 Select process. By selecting a process, input options: the number of grades, the number of silos, the number of packing machines, the maximum capacity of each silo and the connected configuration of silos and packing machines are decided by its default value.

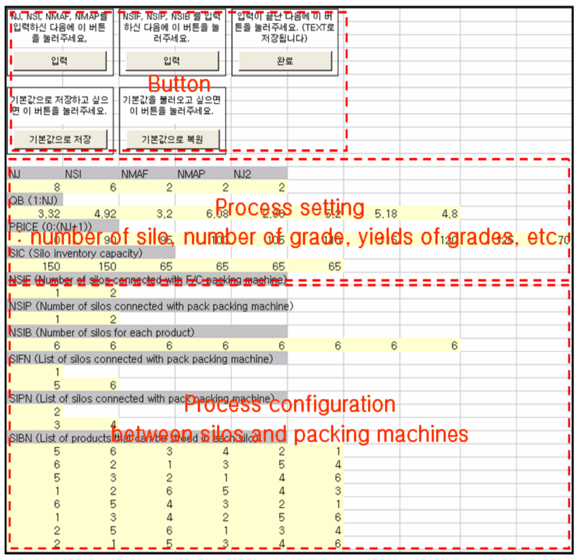

Fig 4 Process setting window

Step 2 Process setting. Fig 4 shows the process setting window. This window can be divided into three parts. The first part consists of buttons: load default values, save default values, confirm input options, etc. The second part presents input options for process parameters: number of grades, number of silos, number of packing machines, processing time for each grade, etc. The third part shows the configuration of silos and packing machines.

Default values of input options can be edited by the user. In order to communicate between three components of this system, text files are used. After this step, input files for both engines are constructed.

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

Step 4 Run the forecasting engine. From D/B, input data for demand forecasting are accomplished. The engine forecasts demand and then determines safety inventory.

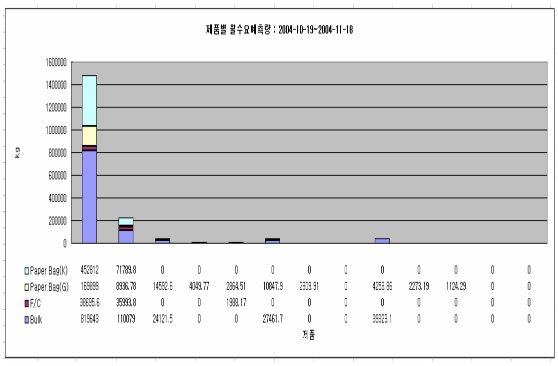

Fig 5 Chart of forecasted demand

Step 5 Visualize forecasted results. The forecasted result window shows charts of forecasted demand, safety inventory, and estimated production amount. The production amount can be calculated using current inventory, forecasted demand, and safety inventory as shown in equation (7).

$$\text{Production amount} = \text{forecasted demand} + \text{safety inventory} - \text{current inventory} \quad (7)$$

Fig 5 shows chart of forecasted demand. Total demand amount and demand amount of each packing type are shown. Exact values are also represented in this chart.

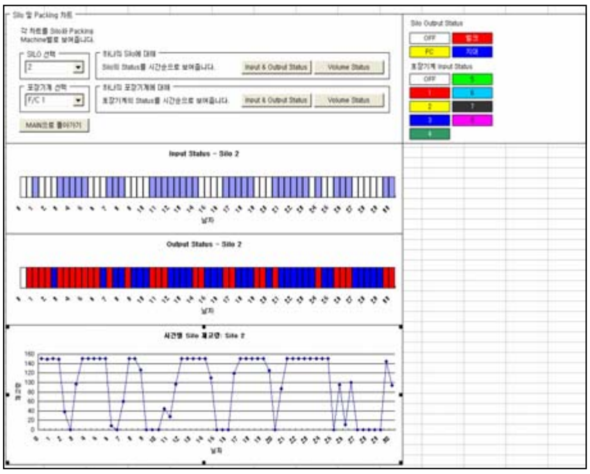

Fig 6. Silo & packing state window

Step 6 Run the scheduling engine. Input files for the scheduling engine can be constructed by three kinds of data: process setting data from step 2, demand data from step 3, and estimated production amount from step 5. The scheduling engine optimizes the PVC scheduling model.

Step 7 Visualize results. After the execution of the scheduling engine, output files are made as the results of optimization. The output files are loaded to EXCEL™. After that, the results are visualized as graphs. Scheduling result windows provide 12 kinds of charts. For example, Fig 6 shows 3 kinds of chart for silo and packing state. In order to check the results in this window, operator should select a silo or packing machine and then press 'input & output status' button and 'volume status volume'. The first and second charts of Fig 6 show input and output states of the selected silo. In these charts, packing types and grades are differentiated by color. The third chart shows bulk PVC volume in the silo.

Step 8 Save results.

6. Example

The mathematical model and the proposed optimization approach were applied to a real PVC process.

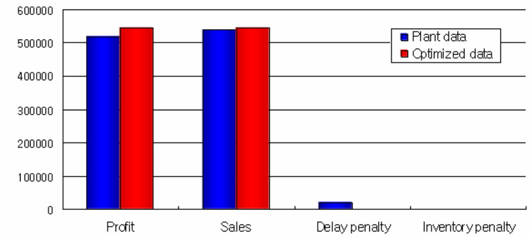

Fig 7 Comparison of the optimization results and the current operation for Process 1

This process produces two grades of PVC and large orders are often placed for these grades. In this process there are 5 reactors, 8 silos, and 3 packing machines. In 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.

As shown in Fig 7, the optimization resulted in 4.6 percent increase profit. This result is obtained in a reasonable amount of time; approximately 5 minutes by a 3.0 GHz PC. This was achieved by reducing the demand delay cost and producing more expensive grades by the results of demand forecasting and safety inventory.

7. CONCLUSION

In this study, an integrated scheduling system with demand forecasting has been developed. The SARIMA (seasonal autoregressive integrated moving average) model is automated to forecast the demand. In order to reduce the cost and instability of production scheduling, a safety inventory determination model is automated additionally. Because most existing forecasting packages require user's knowledge about forecasting, it has been very difficult for plant engineers to apply forecasting packages to scheduling. So the developed automatic forecasting system can help the operators to schedule more efficiently. Safety inventory system will help reduce inventory cost and increase income by reducing the instability of the market.

A scheduling system based on the mathematical model and the efficient optimization approach has been developed. The mathematical model has been proposed for scheduling of the entire process of a PVC (Poly Vinyl Chloride) plant, including production, inventory, packing and shipment. Additionally, more efficient optimization approach has been studied. An efficient algorithm for the scheduling engine can decrease the computational time by reducing the feasible area. Most scheduling problems are NP-hard problems. Thus the computational time to solve the scheduling problems is very long. Therefore reducing the computational time is important factor when we develop a scheduling system.

For validation purposes, a real PVC process is applied. The optimization results showed that the proposed mathematical model and optimization approach 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. Because of the uncertainty in the future demand, the scheduling should be based on the accurate demand forecasting.

The developed system is automated and does not require the user's knowledge about forecasting and scheduling. And the GUI based on EXCEL™, improves user's convenience. Furthermore, this is approximately eight times faster than the manual method. Currently this system is applied to two real PVC processes since 2004. This system can help to reduce required man power for scheduling.

The proposed system is expected to be applicable to other PVC plants, since PVC plants typically have similar configurations. Furthermore, it is expected that it could be applied to other polymerization plants with similar configurations.

8. ACKNOWLEGEMENT

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