Development of PC-based PVC scheduling system connected with ERP system

Min-gu Kang*, Sookil Kang*, Ho-kyung Lee**, and Sunwon Park*

* Department of Chemical & Bilomolecular Engineering, KAIST, Daejeon, Korea (Tel: +82-42-869-3920, E-mail: sunwon@kaist.ac.kr)

**CRD Research Institute, LG Chemical Corporation, Daejeon, Korea

Abstract: These days there are so many scheduling systems or softwares. But only few scheduling systems have succeeded in the market. In spite of powerful engine and functions, those systems have difficulties to be applied in real processes. In real processes, there are various constraints caused by physical or systematical environments of plants. Those constraints are too many to be handled in the system. This problem makes it difficult for the system to represent the details of processes. In order to resolve this problem, we have developed a specialized scheduling system for a target process. The system could be developed by the experts for target process and researchers for scheduling. In this study, a scheduling system for PVC process has been developed as an MILP (Mixed integer linear programming) model and coded in FortranTM. The scheduling system has been applied to two processes, which have different characteristics. Simulation results indicate that the profit of the target process can be increased by about 5% by implementing the scheduling system.

Keywords: At least four keywords separated by commas

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 in real processes. In real processes, there are various constraints caused by physical or systematical environments of plants. Those constraints are too many to be handled in the system. This problem makes it difficult for the system to represent the details of processes.

In order to resolve this problem, we have developed a specialized scheduling system for a target process. The system could be developed by the experts for target process and researchers for scheduling. In this study, a scheduling system for PVC process has been developed as an MILP (Mixed integer linear programming) model and coded in FortranTM.

This system incorporates all processes of PVC production, such as production scheduling, inventory management, and scheduling of packing and shipment. This system focuses on two factors. The first is getting good optimization solution within reasonable time, 5 minutes. The second is that the user could handle the system more easily.

The target process, PVC process, has the ERP (Enterprise Resource Planning) system, which can manage the information about manpower, resource, and products. ERP system also has a tool which can optimize the production scheduling. However, the tool couldn't be used by the reason which is mentioned above. Although some parts of the ERP system become useless, the ERP system still has several advantages for developing the scheduling system. It can supports the optimal environment for the scheduling system, because ERP system has well-defined database and it can supply the needed information in real-time.

The modeling for PVC process is formulated as a MILP. Genetic algorithm and gradient based method are used to solve this model. In order to reduce the calculation time, a method which can reduce the solution area of genetic algorithm is used. This method can estimate the lower bound of the objective value using production sequence. It makes it possible to reduce the solution area.

In this study, the scheduling system has been applied to two processes, which have different characteristics. Simulation results indicate that the profit of the target process can be increased by about 5% by implementing the scheduling system.

2. TARGET SYSTEM

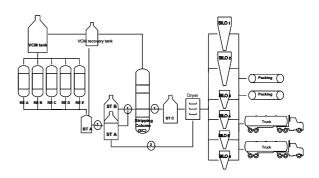


Fig 1. A flow diagram for the PVC plant

A flow diagram for the polymerization process is shown in Fig 1. The PVC plant consists of several reactors, intermediate storage tanks, stripping columns, dryers, silos, and packing machines. The grades of PVCs are specified in the polymerization step and are caused by specific additives. Blow-down tanks (BT) and slurry tanks (ST) are used as intermediate storage tanks which feed into the continuous process. In the stripping column, unreacted VCM is separated and recovered as the feed of the reactors. Due to the high amount of water used for sealing and quenching the reactors, the removal of the water is required in the dryer.

Polymerized PVC is shipped in three ways, these are: F/C, paper bag and bulk. F/C and paper bag types are divided a again into a domestic version and an export version. Bulk type PVC is shipped from the silo directly, whereas the F/C type and paper bag type are shipped from the warehouse after exiting the packing machine.

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).

Profit = Sales - Raw material cost - Demand delay cost - Inventory cost (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_{ii} 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.

Objective value = Sales

- (Demand penalty + Inventory penalty) (24)

Demand penalty + Inventory \geq LBD (25)

UBO = Sales - LBD \geq Objective value (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_{ii} .

Step 7. Select a feasible solution with the UBO. Then go to Step 2.

Step 8. Terminate.

5. SYSTEM DEVELOPMENT

The developed system is 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.

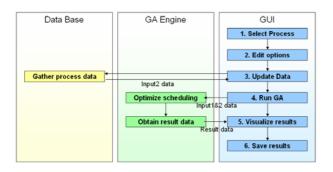


Fig 2. A flow diagram of the developed system

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

٩J	, NSC NIMAF, NIMA		NSIF, NSIP, N		शनवा सन				
22	역하신 다음에 이 H 를 눌러주세요.	as II.	하신 다음에 0 라주셔		문을 불러주네 저장됨:				
!-		- 11							
!_	인력		인데		21	ž.	i		
			But	tton					
	본값으로 저장하고 :		기본값을 둘러	오고 싶으면					
25	이 버튼을 눌러주셔	18.	이 버튼을 늘	리주네요.					
:	기본간으로 저장		기본값으	m M DI			1		
<u>'-</u>	기급및으로 제당	_4.	ALE W.	2 70					
7	NSI		VIMAF	NMAP	NJ2				
140	8	6	2	INMHE 2	2				
QE	B (1:NJ)			D		- cotti	~~		
i.		4.92	3.2	6.08	rocess	semi	9 5.18	4.8	
PE	SICE (0:(NJ+1))	ron	feile	numa	her of	arade	violds	of grad	es, etc76
BIG	C (Silo inventory	/ capac	ity)	TICHIO	oci de	grade	, yioido	Ongida	old, otter
1	150	150	65	65		65			
#	医金属性 电	log ce	nneched wit		ien enehier)				
kis	SIP (Number of s	ilon oo	onnected wit	th nack nac	Lina machina				
1	1	2	ATTRICTOR W	ur puck puc	eng macrino	_			
NS	SIB (Number of s	ilos fo	r each prod						
L	6	6	6	6		6	6	6	
Pili	FN (List of silos	conne	cted with pa	ack packing	machine)				
1	6	6							
SIF	PN (List of silos	conne	cted with pa	ac <mark>i</mark> napkipo	machine).	nfigu	ration		
!	2			FIOC	633 CC	/illigu	allon		
010	3 BN (List of produ	b	etwee	an eile	bne en	nacki	ina mac	hines	
Pile	5	6	3	4	2	paciti	ing inac	, III 100	
!	6	2	1	3	5	4			
	6	3	2	1	4	6			
	-				4	3			
ŀ	1	2		9					
ŀ	6	2 5 3	4	9	2	1 6			
	1 6 1 2	2 5 3 5	4 4 6	3 2	5 3	1 6 4			
	1 6 1 2 - 2	2 5 5 5	4 4 6 5	3 2 1 2 2 2	2 5 3 4	1 6 4 6			

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.

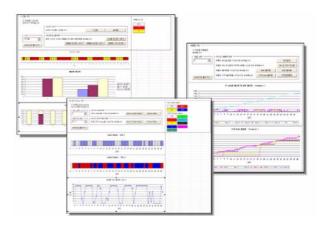


Fig 4. The optimization result graphs

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.

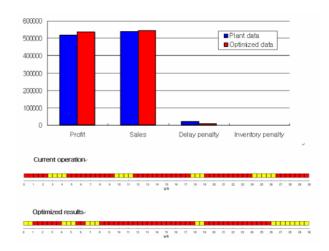


Fig 5. Comparison of the optimization results and the current operation for Process 1

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.

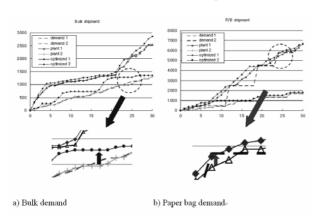


Fig 6. Reduced demand delay cost in integrated inventory and shipment amount for Process 1

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.

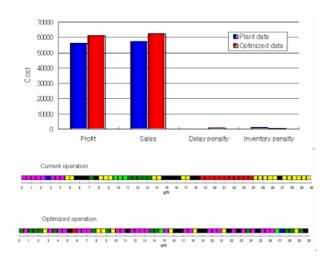


Fig 7. Comparison of the optimization results and the current operation for Process 2

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.

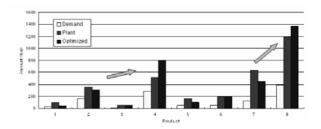


Fig 8. Production amount and demand for Process 2

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. ACKNOWLEGEMENT

This work was partially supported by the IMT 2000 (project number: 00015993), Center for Ultramicrochemical Process Systems sponsored by KOSEF and BK21

9. REFERENCE

[1] Shah., N, Liberis, L., Izumoto, E., and Henson, R., Integrated batch plant design: A polymer plant case study, *Computers and Chemical Engineering*, 20, Suppl 2, s1233-s1238 (1996)

- [2] Bretelle, D., Chua, E. S., and Macchietto, S., Simulation and on-line scheduling of a PVC process for operator training, *Computers and Chemical Engineering*, 53, 2, 157-170 (1997)
- [3] Naarur, N., Vrat, P., and Duongsuwan, W., Production planning and scheduling for injection moulding of pipe fittings, *International Journal of Production Economics*, 53, 157-170 (1997)
- [4] Luo, Y., Guignard, M., and Chen, C., A hybrid approach for integer programming combining genetic algorithms, *linear programming and ordinal optimization, Journal of Intelligent Manufacturing*, 12, 509-519 (2001)
- [5] Dahal, K. P., Burt, G. M., McDonald, J. R., and Moyes, A., A case study of scheduling storage tanks using a hybrid genetic algorithm, *IEEE Transactions on Evolutionary computation*, 5(3), 283-294 (2001)
- [6] Zhou, J., and Liu, B., New stochastic models for capacitated location-allocation problem, *Computer and Industrial Engineering*, 45, 111-125 (2003)
- [7] Parsons, D. J., Optimizing silage harvesting plans in a grass and grazing simulation using the revised simplex method and a genetic algorithm, *Agricultural Systems*, 56(1), 29-44 (1998)
- [8] Goldberg, D. E., Genetic algorithm in search, optimization, and machine learning, *Addison-Wesley publishing company* (1989)
- [9] Korea Petrochemical Industry Association, The demand and the shipment for major petrochemical products, *Petrochemical Bulletin*, 4, 72 (2004)
- [10] Chemical market research inc., Petrochemical profile, *Chemical Journal Weekly*, 13, 26, 2 (2003)
- [11] Kang, M, Moon, S., Kang, J., and Park. S., Integrated scheduling model for PVC process, *ICCAS2003* (2003)